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CIVIL EFFECTS STUDY

AERORADIOACTIVITY SURVEY AND AREAL GEOLOGY OF THE DISTRICT OF COLUMBIA AND PARTS OF MARYLAND, VIRGINIA, AND WEST VIRGINIA (ARMS-I)

Sherman K. Neuschel

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AERORADIOACTIVITY SURVEY AND AREAL GEOLOGY OF THE DISTRICT OF COLUMBIA AND PARTS OF MARYLAND, VIRGINIA, AND WEST VIRGINIA (ARMS-I)

By

Sherman K. Neuschel

Approved by: Director
U. S. Geological Survey

Approved by: L. J. DEAL, Chief
Civil Effects Branch

U. S. Geological Survey
and
Division of Biology and Medicine, USAEC
May 1963

NOTICE

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ABSTRACT

An aeroradioactivity survey of approximately 8000 square miles near Washington, D. C. was made by the U. S. Geological Survey on behalf of the U. S. Atomic Energy Commission. Radioactivity profiles were obtained using scintillation-detection equipment along parallel, mile-spaced, east-west flight lines approximately 500 ft above the ground. A map of aeroradioactivity units compiled from the profiles shows a wide range of radioactivity and a generally excellent correlation of radioactivity to areal geology.

Parts of four physiographic provinces were covered: the Coastal Plain, Piedmont, Blue Ridge, and Appalachian Valley of the Ridge and Valley province. Radioactivity units for each province have characteristic values and a pattern that reflects the geologic structure.

The Coastal Plain has predominantly low radioactivity levels, 100 to 400 cps (counts per second). Higher radioactivity (400 to 650 cps) is associated with glauconitic sand of the marine Upper Cretaceous or with detrital material that was derived from the nearby Piedmont.

The Piedmont and Blue Ridge provinces have a wide range of radioactivity (100 to 1500 cps) because of the great variety of rocks. In general, low values (100 to 300 cps) are found over sandstone, quartzite, and mafic rocks. Areas underlain by shale, limestone, phyllite, schist, and gneiss have intermediate values of 400 to 600 cps. Highest radioactivity (more than 600 cps) is associated with granite and gneiss.

In the Appalachian Valley radioactivity is moderate to high (400 to 850 cps), and the units distinctly parallel the regional strike. The higher radioactivity is associated with shale and lower values with calcareous rocks.

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1. INTRODUCTION

1.1 Location of Area and Purpose of Survey

An aeroradioactivity survey of the District of Columbia and parts of Maryland, Virginia, and West Virginia, was made by the U. S. Geological Survey in cooperation with the Division of Biology and Medicine, U. S. Atomic Energy Commission between Feb. 1 and May 4, 1960. This survey is part of the Aerial Radiological Measurement Surveys (ARMS-I) program. An area of approximately 8000 square miles centered on the Fort Belvoir nuclear facility in Virginia, approximately 12 miles southwest of Washington, D. C., was surveyed on mile-spaced, east-west flight lines 500 ft above ground level. The boundaries of the area are Chesapeake Bay, 78° 00'W. longitude, 37° 55' and 39° 25' N. latitude (Fig. 1).

1.2 Airborne Survey Procedure

The survey was made with scintillation-detection equipment installed in a twin-engine aircraft. Parallel east-west flight lines spaced 1 mile apart are oriented nearly perpendicular to the general north-northeast geologic trend of the area. The aircraft maintained an approximate altitude of 500 ft above the ground at an average air speed of 150 mph. Topographic maps and county road maps were used for pilot guidance. The flight path of the aircraft was recorded by a gyrostabilized continuous-strip-film camera, and the distance of the aircraft from the ground was measured by a continuously recording radar altimeter. Fiducial markings providing a common reference for the radioactivity and altimeter data and the camera film were made with an electromechanical edge-mark system operated by the flight observer when the aircraft passed over recognizable features on the ground.

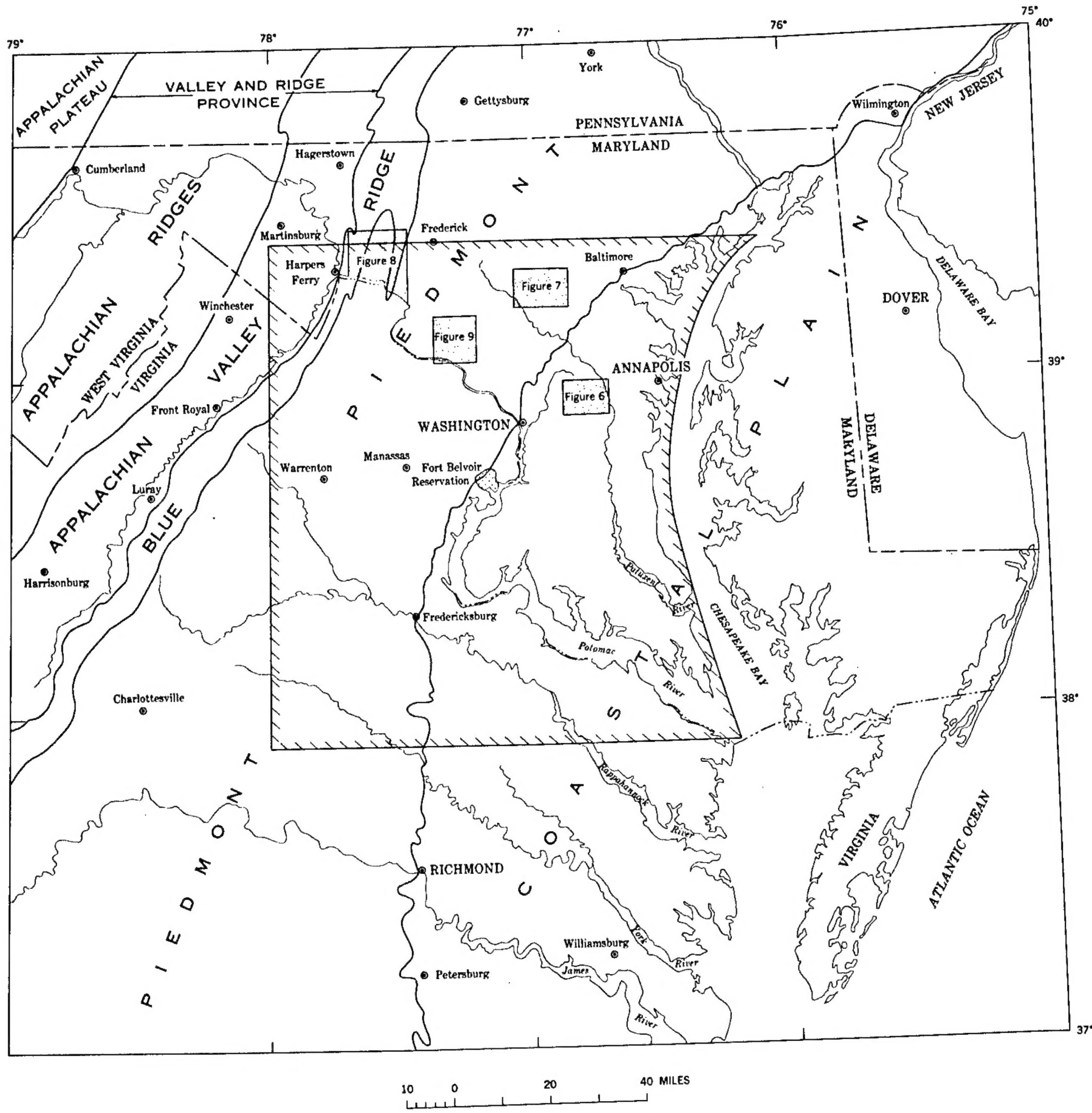


Fig. 1—Index map showing physiographic provinces and location of the area covered in the aeroradioactivity map of the Washington, D. C., area and Figs. 6, 7, 8, and 9.

1.3 Scintillation Detection Equipment

The gamma radiation detection equipment used by the Geological Survey was designed by the Health Physics Division of the Oak Ridge National Laboratory and has been discussed in detail by Davis and Reinhardt[1,2]. In describing the sensitivity of the equipment they state: "...with a microgram of radium at one foot from the crystals, the counting rate is roughly 2,000 cps (counts per second)" (Ref. 1, p. 717). Kermit Larsen[3] determined in 1958 that a count rate of about 77,000 cps would be recorded by the Geological Survey equipment 500 ft above a virtually infinite area of fallout that produced a gamma-ray flux of 1 mr/hr (milliroentgen per hour) at 3 ft above the ground. This comparison was made over an infinite fallout source, the source being of infinite dimension insofar as the area of response of the airborne equipment is concerned.

A diagram of the equipment is shown in Figure 2. The detecting element consists of six thallium-activated sodium iodide crystals, 4 in. in diameter and 2 in. thick, and six photomultiplier tubes connected in parallel. The signal from the detecting element is fed through amplification stages to a pulse-height discriminator that is usually set to accept only pulses originating from gamma radiation with energies greater than 50 kev (thousand electron volts). The signal from the discriminator is then fed to two rate meters. One rate meter feeds a circuit that records total radioactivity on a graphic milliammeter. The signal from the other rate meter is recorded by a circuit that includes a variable resistance, which is controlled by the radar-altimeter servomechanism. This arrangement approximately compensates the data for deviations from the nominal 500 ft surveying altitude. The cosmic background is removed before the data are compensated.

The crystals are shielded on the sides by 0.5 in. of lead, which negates any influence of the radium-dial instruments in the aircraft. The effective area of response at an elevation of 500 ft is approximately 1000 ft in diameter, and the radioactivity recorded is an average of the radioactivity received from within this area. Theoretical aspects of the area of response and other considerations are discussed by Sakakura[4], Moxham[5], and Gregory[6].

The gamma-ray flux at 2000 ft above the ground, which comes from cosmic radiation and to a much lesser extent from radionuclides in the air, except after nuclear tests, is measured twice each day during the surveying. This quantity is called the cosmic background at 2000 ft. Theoretically, the cosmic background at 500 ft is nine-tenths that at 2000 ft, and the compensated data have had this nine-tenths of the cosmic component removed. The average cosmic background measured at 2000 ft during the Washington, D. C. survey was about 300 cps. A portion of a regular flight line, called a test line, is flown at the normal survey altitude at the beginning and the end of surveying each day. An approximation of the amount of diurnal variation of atmospheric radionuclides can be obtained by comparing these data.

1.4 Theoretical Considerations

The gamma-ray flux at 500 ft above the ground has three principal sources: cosmic radiation, radionuclides in the air (mostly radon

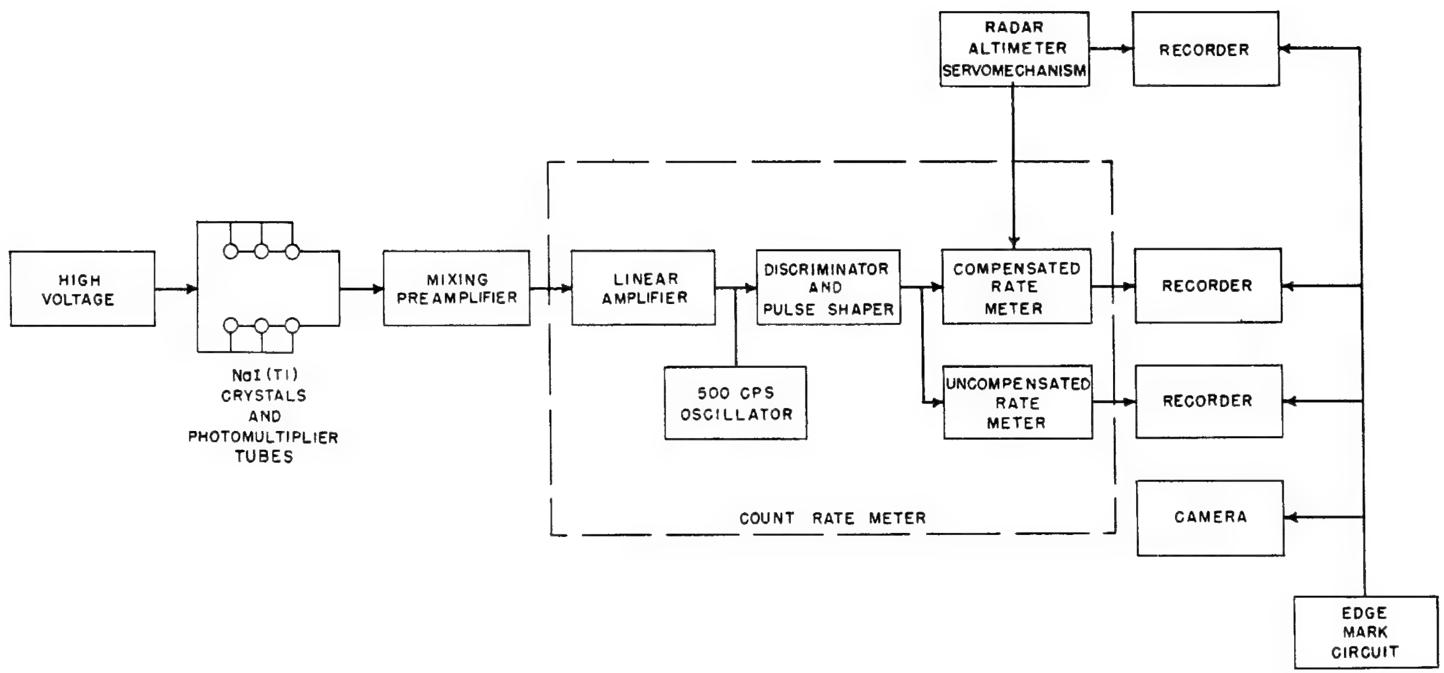


Fig. 2—Diagram of airborne radioactivity survey equipment.

daughter products), and radionuclides in the surficial layer of the ground. As discussed in Sec. 1.3, it is possible to estimate the contribution of the cosmic component. However, the component due to radionuclides in the air at 500 ft above the ground cannot be separated from the ground component. It is affected by meteorological conditions, and a tenfold change in radon concentration is not unusual under conditions of extreme temperature inversion. Values for diurnal variation cannot be obtained from test-line data flown at the beginning and end of each day since 450 to 600 traverse miles may be flown during an average flight of 4 to 6 hours. The air component, if inversion conditions are avoided, may be considered to be fairly uniform on a given day in a particular area.

The ground component comes from the upper few inches of rock and soil, and consequently the influence of a thin surficial veneer of wind-transported material may be relatively high. The ground component consists of gamma rays from natural radionuclides (principally K^{40} and members of the uranium and thorium radioactive decay series) and radioactive fission products in fallout. The distribution of fallout in the Washington, D. C. area is assumed to be uniform and must be small, because the lowest total radioactivity (not affected by water) measured in the area is 100 cps. Gustafson, Marinelli, and Brar[7], for example, concluded from a study of the radioactivity of soil from Lemont, Ill., that in the spring of 1957 the activity due to fallout was less than one-tenth the total gamma activity of the soil. Although the Operation Plumbbob tests in 1957 produced considerable fallout, data from periodic resurveys of test lines in Virginia, Texas, and New Mexico by the Geological Survey[8] indicate that fallout probably accounts for much less than 100 cps of the background gamma radioactivity of those areas.

The present distribution and concentration of natural radionuclides in the surficial material are determined by the original content and form of the radioactive material in the parent rock and by changes brought about by geologic and soil-forming processes. An important consideration in studying the radioactivity of a soil is whether it is a residual soil, which is derived from the rock beneath it, or a transported soil, which may be derived from rocks entirely different from that on which the soil rests. Although complete studies of the distribution of natural radionuclides for different types of soil and rock have not been made, information on individual mineral components is available. Radioactive heavy minerals, such as monazite, a rare-earth phosphate containing as much as 30 percent thorium; and zircon, a zirconium silicate containing as much as 1 percent uranium, are present in small quantities in many types of rocks and soils.

The concentration of these minerals at the surface of a residual soil may be greater or less than their concentration in the parent rock, depending upon the interplay of the various soil-forming processes, but generally the radioactivity level measured is close to that of the bedrock. Uranium and thorium, and their daughter products, are commonly present in rock and soil in amounts ranging from traces to several parts per million. The content of all potassium isotopes of the surficial layer may be as much as several percent, of which K^{40} (the only naturally occurring radioactive

potassium isotope) is only a minute part. Rough averages for the amounts of these elements in common rocks in parts per million (ppm) are shown in Table 1 (adapted from Turekian and Wedepohl[9]).

Table 1 - APPROXIMATE AMOUNTS OF URANIUM, THORIUM, AND K^{40} IN COMMON ROCKS

Rock	Uranium, ppm	Thorium, ppm	K^{40}, ppm
Granitic rock	3	8.5-17	3.5
Basaltic rock	1	4	1
Sandstone	0.45	1.7	1.3
Shale	3.7	12	3
Carbonate rock	2.2	1.7	0.3

1.5 Compilation of Aeroradioactivity Data

The altitude-compensated aeroradioactivity profiles were used in the preparation of the map "Natural gamma aeroradioactivity of the District of Columbia and parts of Maryland, Virginia, and West Virginia" (Pl. 1). This map is also published in the Geological Survey's Geophysical Investigations Map Series[10].

Flight-line locations from the strip-film obtained during the course of surveying were plotted on the compilation base maps at a scale of 1 in. equals about 1 mile (1:62,500). Radioactivity profiles from adjacent flight lines were examined and changes or breaks in the level of radioactivity record were correlated from line to line. The changes of the radioactivity record are indicated on the map (Pl. 1) by solid or dashed lines, depending on the degree of correlation. The difference between the lines is a matter of degree, the solid lines denoting distinct or sharp changes in level of radioactivity, the dashed lines relatively less distinct, generally transitional changes. Areas enclosed by lines of change were assigned general ranges of radioactivity levels by scanning the records obtained over the specific areas. The lines of change and the radioactivity levels were plotted along flight lines on transparent overlays of the compilation base maps. These overlays were reduced to a scale of 1 in. equals about 4 miles (1:250,000), and the data were plotted on sheets of the Geological Survey 1:250,000-scale topographic map series. The final map (Pl. 1) was thus derived, showing radioactivity levels and lines of change and major cultural and drainage features. The various patterns of green on the map indicate approximate ranges of radioactivity and are meant to facilitate reading of the map. Figure 3 is a generalized version of the same map.

2. GENERAL GEOLOGY

The Washington, D. C. area contains portions of four major physiographic provinces: (1) the Coastal Plain, underlain by gently southeastward dipping, relatively unconsolidated sedimentary rocks of Early Cretaceous to Pleistocene age; (2) the Piedmont, underlain by steeply inclined sedimentary, metamorphic, and igneous rocks of Precambrian to Triassic age; (3) the Blue Ridge, narrow northeast trending mountain ridges, composed of resistant Lower Cambrian quartzite and phyllite; and (4) the Appalachian Valley, a lowland area, developed on steeply dipping Cambrian and Ordovician limestones, dolomites, and shales. The rocks in all four physiographic provinces strike rather uniformly N. 20° - 25° E.

The generalized geologic map (Fig. 4) was compiled from published maps. For the Maryland and West Virginia portions of the area, county maps at a scale of 1:62,500 were used. This detail makes possible fairly reliable correlations between geology and aeroradioactivity in these areas. The Virginia portion was compiled from the 1928 state geologic map[11] which is on a scale of 1:500,000, and very few valid detailed correlations are possible. The 1963 geologic map[12] of Virginia was not available until completion of this manuscript. It is important to note, however, that in the area covered by this aeroradioactivity study, the recent geologic map has only a very few minor changes from the 1928 mapping.

3. GENERAL DISTRIBUTION OF AERORADIOACTIVITY

3.1 Washington, D. C. Survey Area

The natural gamma radioactivity of the Washington, D. C. area ranges from 100 to 1500 cps. The 1:250,000 radioactivity map (Pl. 1) divides the area into eleven units of different levels of radioactivity. All changes in levels are due to the varying isotope content of the rocks and residual soils.

Most of the Coastal Plain has uniformly low radioactivity levels of 100 to 400 cps. In Prince Georges and Anne Arundel Counties, Md. (east of Washington, D. C.), Upper Cretaceous rocks are more radioactive (400 to 600 cps) than the rest of the stratigraphic units of the Coastal Plain. Also along the Rappahannock River in Virginia and in an area just east of Fredericksburg, Va., the radioactivity values are higher.

The Piedmont and Blue Ridge provinces have a wide range of radioactivity, 100 to 1500 cps, because of the great variety of rocks. In general, low values, 100 to 300 cps, are found over sandstone, quartzite, and mafic rocks such as basalt, gabbro, and serpentine. Areas underlain by shale, gneiss, schist, or phyllite have intermediate values of 400 to 600 cps. Highest radioactivity of more than 600 cps is associated with granite and the Baltimore Gneiss.

In the Appalachian Valley radioactivity ranges from 400 to 850 cps, and the different units are in distinct north-northeast trending

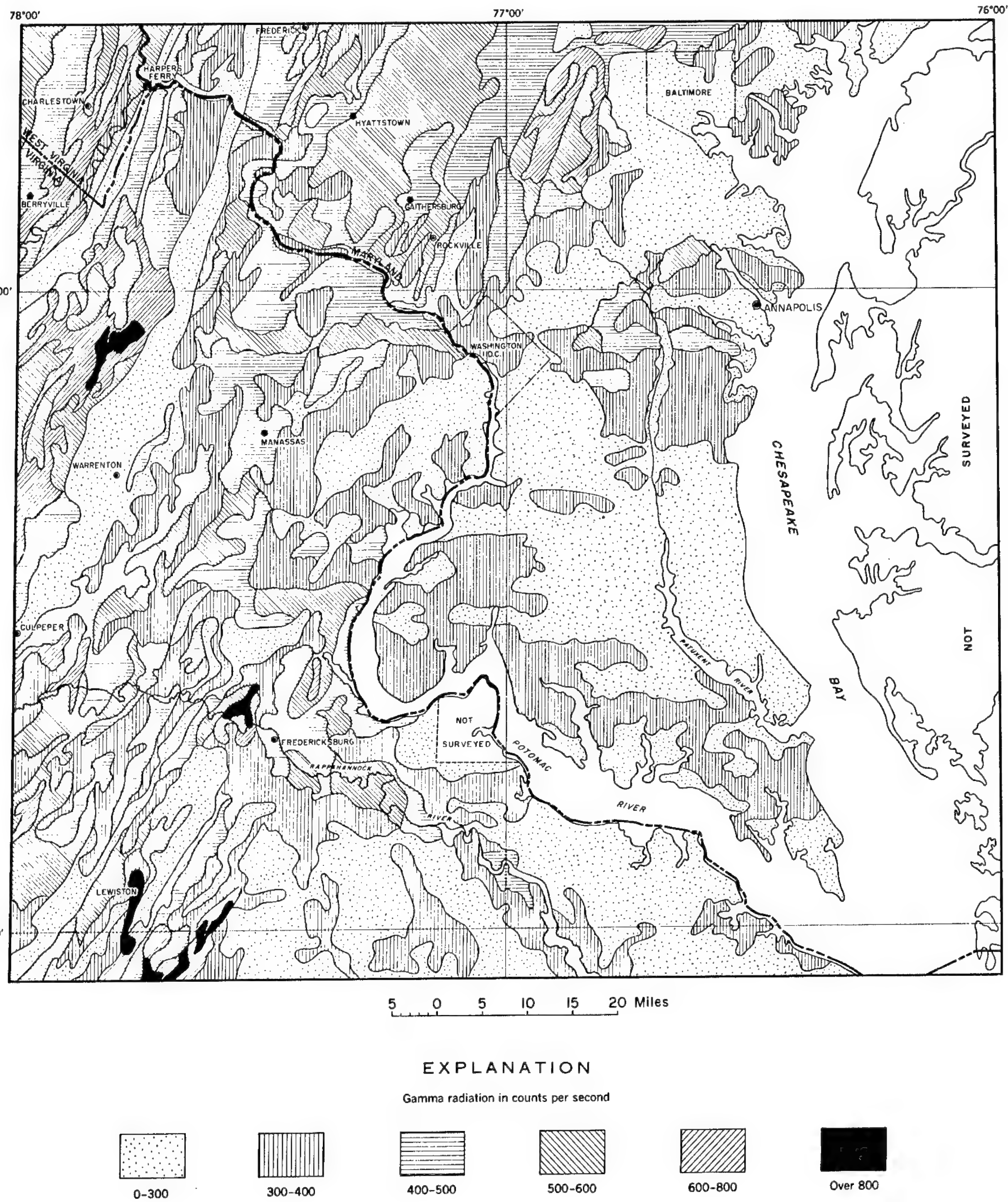
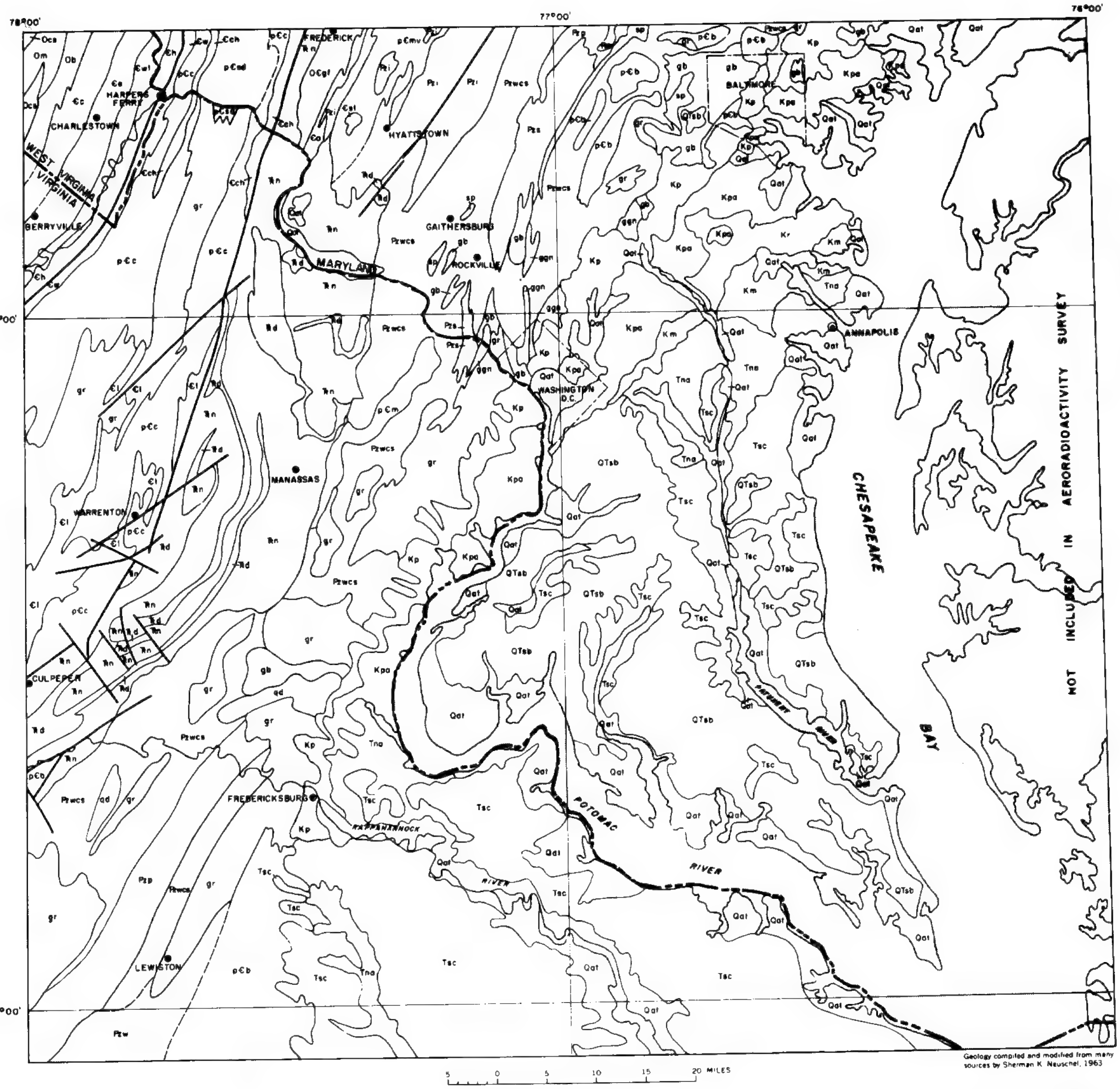


Fig. 3 — Generalized aeroradioactivity map of Washington, D. C., and vicinity.



Rece

Sun

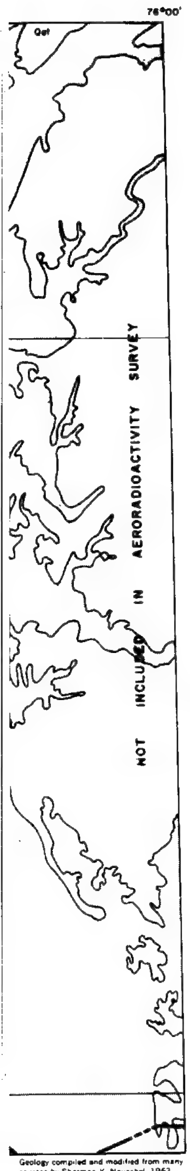
Chesapeake Group

St. Mar

Pamunkey Group

Pat

Fig. 4—Generalized geologic map of Was



EXPLANATION

QUATERNARY

- Qat — Recent alluvium, Wicomico Formation, and Talbot Formation
- QTsb — Sunderland and Brandywine Formations

TERTIARY

- Tsc — Chesapeake Group: St. Marys, Choptank, and Calvert Formations
- Tna — Pamunkey Group: Nanjemoy and Aquia Formations

CRETACEOUS

- Km — Monmouth, Matawan, and Magothy Formations
- Kr — Raritan Formation
- Kpa — Patapsco Formation and Arundel Clay
- Kp — Patuxent Formation

TRIASSIC

- ₮n — Newark Group

ORDOVICIAN

- Om — Martinsburg Shale
- Ocs — Chambersburg and Stones River Limestones
- Ob — Beekmantown Group
- O€gf — Grove Limestone and Frederick Limestone

CAMBRIAN

- €c — Conococheague Limestone
- €e — Elbrook Limestone
- €wt — Waynesboro Formation and Tomstown Dolomite

CAMBRIAN(?)

- €sl — Sugarloaf Mountain Quartzite
- €ch (€a, €h, €w, €l) — Chilhowee Group
  - *€a, Antietam Quartzite*
  - *€h, Harpers Phyllite*
  - *€w, Weverton Quartzite*
  - *€l, Loudoun Formation*

PALEOZOIC

- Pzs — Sykesville Formation

PALEOZOIC(?)

- Pzp — Peters Creek Quartzite
- Pzi — Glenarm Series: Ijamsville Phyllite
- Pzwcs, Pzw — Wissahickon Formation, Cockeysville Marble, and Setters Formation; Pzw, Granitized gneiss of Wissahickon Formation in Virginia

PRE-CAMBRIAN

- p€b — Baltimore Gneiss

IGNEOUS ROCKS

TRIASSIC

- ₮d — Diabase

AGE UNKNOWN

- gr — Granite
- qd — Quartz diorite
- ggn — Granite gneiss
  Includes Kensington Granite-Gneiss of Cloos (1951) and Laurel Gneiss of Chapman (1942) in Maryland
- sp — Serpentine
- gb — Gabbro

PRECAMBRIAN

- p€mv — Metavolcanic rocks
  Mostly metarhyolites and metaandesites
- p€c, p€m — Catoctin Metabasalt and other metabasalts; p€m, other metabasalts
- p€sd — Mica schist and hornblende diorite
  Called injection complex

Geologic contact
Dashed where inferred

Fault

alized geologic map of Washington, D. C., and vicinity.

2

bands that parallel the regional strike. Higher radioactivity is associated with shale and shaley limestone and lower values with limestone and dolomite.

Throughout the Washington, D. C. area the linear pattern of units on the aeroradioactivity map (Fig. 3 and Pl. 1) shows a remarkable correlation with the north-northeast strike of the rock units on the generalized geologic map (Fig. 4), and there are many distinct radioactivity breaks that can be related directly to known geologic contacts. Indeed the area is an excellent one for the study of the relation between aeroradioactivity and geology. The correlation of radioactivity with geology can be easily demonstrated in the Piedmont province of Maryland. It is probable that more detailed geologic mapping in the state of Virginia would show the same excellent association of radioactivity boundaries to geologic contacts. Figure 5 shows a diagrammatic cross section of the physiographic provinces of the Washington, D. C. area with typical geology and associated aeroradioactivity.

3.2 Fort Belvoir Reactor

On May 4, 1960, six traverses were made over the Fort Belvoir reactor. Flights intersecting approximately over the reactor site were made on northeast-southwest and northwest-southeast azimuths. At each azimuth three passes were made, each at a different altitude, 250, 500 and 750 ft above ground level. The airborne equipment measured the maximum effect of the reactor only at the 250 ft altitude where the compensated recorder indicated 8500 cps (this measurement is not shown on Pl. 1). This high reading results from normal atomic energy operations at the Fort Belvoir facility. Radioactivity measurements over the Fort Belvoir reactor area made from higher elevations fall within the general level (200 to 400 cps) of the Pliocene and Pleistocene alluvial terraces of the surrounding Coastal Plain.

4. CORRELATION OF AERORADIOACTIVITY TO GEOLOGY

4.1 Coastal Plain Province

The part of the Washington, D. C. study area, east of a line drawn through Baltimore, northwest Washington, D. C., and Fredericksburg, Va., lies entirely within the Coastal Plain. It is a relatively low-lying region where relief seldom exceeds 100 or 200 ft. Elevations vary from sea level to about 400 ft at the western limit.

The Coastal Plain is underlain by a wedge-shaped sequence of relatively unconsolidated and undeformed sediments, Early Cretaceous to Pleistocene in age, which dip eastward at 10 to 40 ft per mile. Stratigraphic units consist of marl, clay, silt, sand, and gravel, and lie on an eastward-sloping floor of older crystalline rocks (gneiss and schist) which crop out in the Piedmont province to the west.

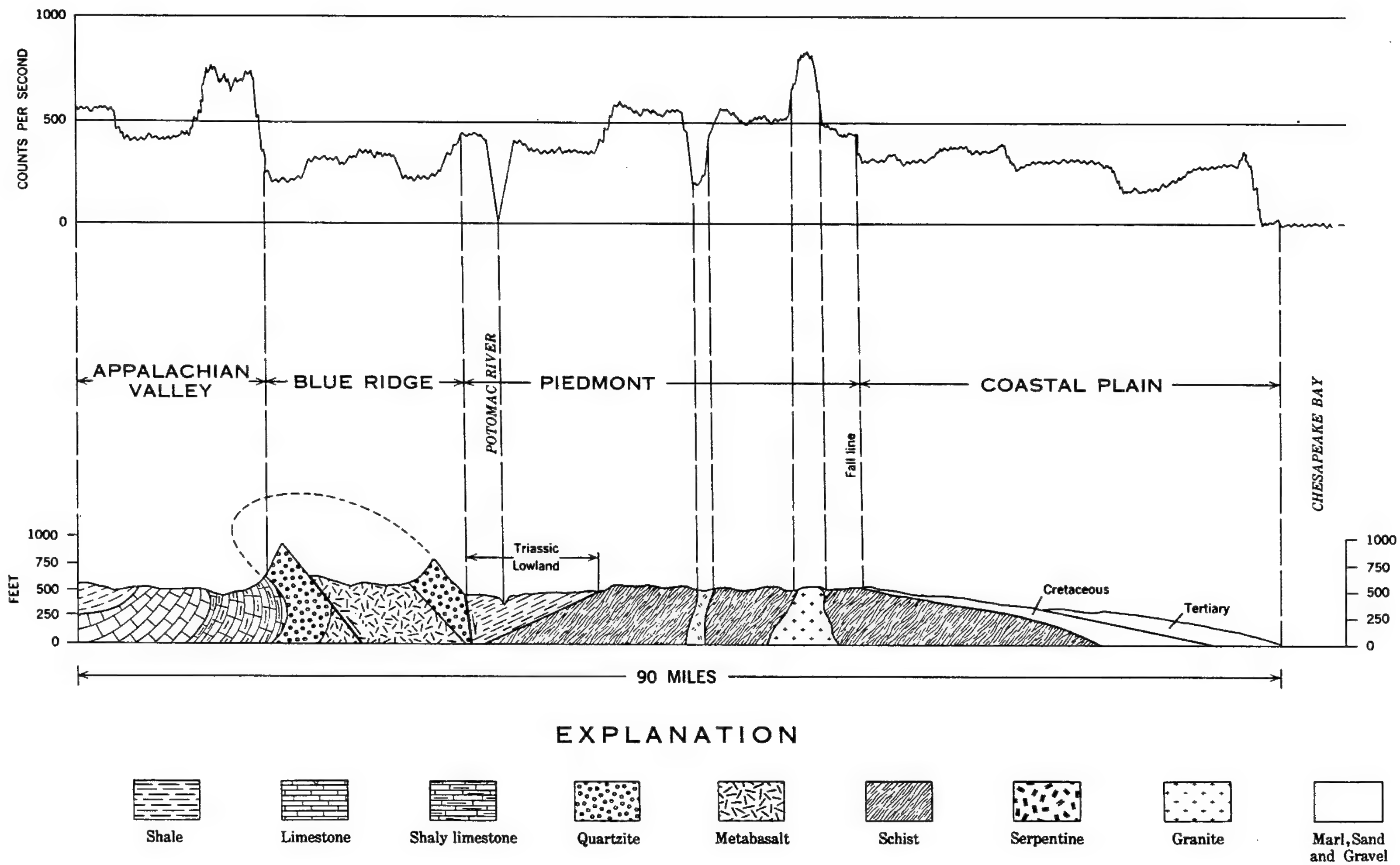


Fig. 5—Diagrammatic cross section of the rocks in the vicinity of Washington, D. C., and typical associated aeroradioactivity.

The Potomac Group of Early and Late Cretaceous age comprises the basal sedimentary rocks of the Coastal Plain in Maryland and Virginia and includes the Patuxent and Patapsco Formations, which consist of unconsolidated continental sand and gravel with some clay. These rocks crop out in two parallel bands at the western margin of the Coastal Plain from the northern part of the area to the Rappahannock River in the south. The Upper Cretaceous, which includes the Raritan, Magothy, Matawan, and Monmouth Formations, is a series of unconsolidated sands with some varigated clay and sandy clay, which crop out only in the Maryland portion of the surveyed area. The two upper formations, the Matawan and Monmouth, are marine clays and green sands that can be distinguished from the other Cretaceous sediments by the abundance of the green mineral glauconite. Overlying the Cretaceous are the Aquia and Nanjemoy Formations (Pamunkey Group) of lower and middle Eocene age, which consist of sandstone, sand, and clay. The Chesapeake Group of Miocene age consists of clays and sands and includes the Calvert, Choptank, and St. Marys Formations. Overlying all the older deposits of the Coastal Plain is a series of gravels and sands which were laid down as terrace deposits or valley fill. These deposits include the Brandywine Formation of Pliocene(?) age, which in places overlies the crystalline rocks of the Piedmont; the Sunderland, Wicomico, and Talbot Formations of Pleistocene age; and stream alluvium of Recent age.

The distribution of the Coastal Plain units is mapped in detail on the county geological maps for Anne Arundel[13], Calvert[14], Charles[15], Prince Georges[16], and St. Marys Counties[17]. Coastal Plain geology has been described by Cooke[18], Darton[19,20]; Dryden and Overbeck[21]; and Stephenson, Cooke, and Mansfield[22].

Most of the Coastal Plain has uniformly low radioactivity levels of 100 to 400 cps and stands out in strong contrast with the rest of the Washington, D. C. area, which has distinct northeast trending bands of low and high radioactivity. With the exception of a few areas, it is not possible, at least with mile-spaced flight lines, to delineate geologic formations in the Coastal Plain.

In southern Anne Arundel and eastern Prince Georges Counties, Md., a large almost circular area about 20 miles in diameter has an aeroradioactivity of 300 to 600 cps notably higher than the surrounding area of the Coastal Plain. This area of higher radioactivity is underlain by the Monmouth and Aquia Formations, both of which are glauconitic sands. The abundant glauconite, which is high in potassium, probably accounts for the higher radioactivity of this area. Figure 6 shows the detailed geology and aeroradioactivity of a small area around Buena Vista in eastern Prince Georges County. The radioactivity is highest, 400 to 600 cps, where the Monmouth Formation is exposed. Radioactivity of the Patapsco Formation to the northwest is 250 to 350 cps and the change in levels is at the exposed contact between the two formations. Also, there is a sharp change in level of radioactivity at the contact of the Monmouth with the Aquia Formation. The Aquia in this area has a radioactivity of 350 to 500 cps which is slightly lower than the more glauconitic Monmouth rocks.

Two other areas of the Coastal Plain have abnormally high aeroradioactivity. From Fredericksburg northeast to the Potomac River radioactivity values are 400 to 700 cps. Along the

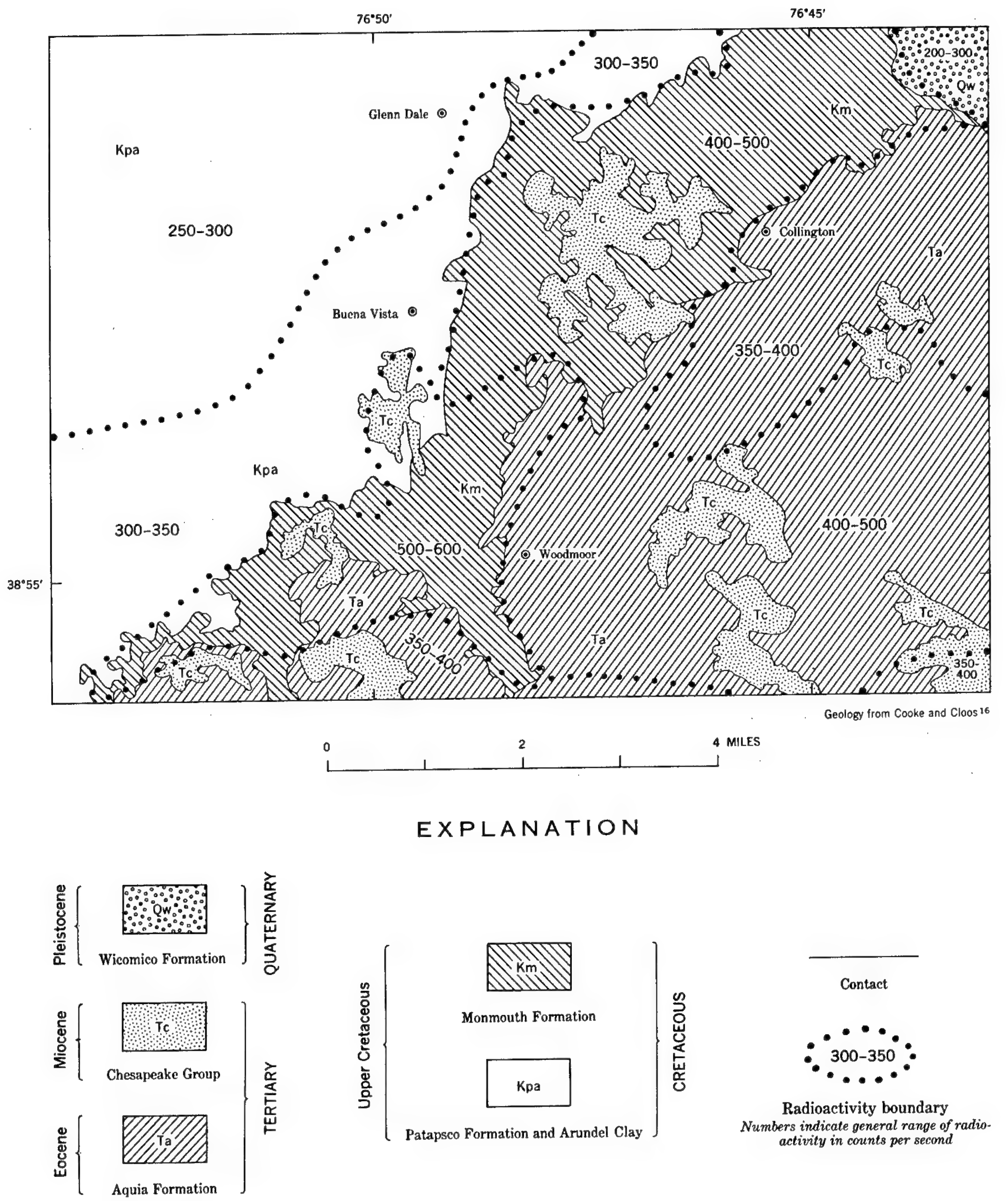


Fig. 6—Geologic and aeroradioactivity map of the Buena Vista area, Prince Georges County, Maryland.

Rappahannock River from Fredericksburg to the southern edge of the surveyed area, a strip 4 to 6 miles in width has an aeroradioactivity of 400 to 600 cps, which contrasts with the 200 to 300 cps of the adjacent Coastal Plain. Immediately west of Fredericksburg, Va., in the Piedmont province, the Rappahannock River for about 10 miles crosses the Petersburg Granite and other granites which are among the most radioactive rocks of the Washington, D. C. area, with values up to 1100 cps. It is probable that the area of higher radioactivity along the Rappahannock River is over stream valley alluvium which contains radioactive detrital material derived from the granitic areas upstream. Similarily, the higher values in the area northeast of Fredericksburg reflect the presence of material within the Pleistocene terrace deposits derived from the granites to the west.

4.2 Piedmont and Blue Ridge Provinces

The Piedmont physiographic province is a northeast trending belt, 40 to 65 miles in width, of steeply inclined, sedimentary, metamorphic, and igneous rocks of Precambrian to Triassic age. The southeast boundary is the Fall Line where the relatively unconsolidated sedimentary rocks of the Coastal Plain overlap the older rocks of the Piedmont. The western boundary is at the foot of ridges of the Blue Ridge province (Catoctin Mountain in Maryland and the Blue Ridge Mountains in Virginia). The Piedmont is in general a moderately dissected, gently rolling upland, with an average altitude of 350 to 650 ft. There are a few low ridges that are erosional remnants developed on relatively more resistant rocks. Within the upland area are two extensive lowland areas: (1) the Frederick Valley in Maryland is developed on Cambrian and Ordovician limestones and has a general elevation of 300 ft; (2) the Triassic Lowland in Maryland and Virginia is developed on sandstone and shale and has a general elevation of 500 ft.

The geology of the Piedmont is extremely complex. Pre-Triassic rocks include many kinds of gneiss and schist, amphibolite, quartzite, and marble, which have been intruded at different times by gabbro, serpentine, granite, granodiorite, quartz diorite, and diabase. These rocks, except for the youngest intrusives, have undergone one or more periods of deformation during the Paleozoic Era. Triassic rocks include red shale, sandstone, and conglomerate which have been broken by faults and intruded by diabase but are essentially unmetamorphosed.

The Blue Ridge province in the area studied is a belt 4 to 11 miles wide containing north-northeast trending ridges which rise abruptly above the level of the Piedmont province to the east and the Appalachian Valley to the west. In the Virginia portion the province consists of a single ridge about 1500 ft in elevation. In the Maryland portion of the area surveyed the Blue Ridge consists of three parallel ridges. The northern extension of the Blue Ridge Mountains of Virginia is known in Maryland as Elk Ridge, which terminates just north of the area surveyed. About three miles to the east is South Mountain, 1200 ft in elevation. Eight miles to the east of South Mountain is Catoctin Mountain, 1000 ft in elevation. To the north of the area surveyed Catoctin Mountain and South Mountain merge to

form a broad mountain upland 8 to 10 miles in width and 1800 ft in elevation. The ridges are formed on the lower Paleozoic clastic deposits of the Chilhowee Group of which the resistant Weverton and Antietam Quartzites are the most important ridge formers.

The Piedmont and Blue Ridge provinces have a wide range of radioactivity, 100 to 1500 cps, because of the great variety of rocks. Most of the area has moderate radioactivity (400 to 600 cps) developed over limestone, shale, schist, and phyllite. Extensive areas of low radioactivity (100 to 300 cps) are found over sandstone, quartzite, and mafic rocks such as basalt, gabbro, and serpentine. Highest levels are associated with granite and granite gneiss (over 600 cps).

Rocks strike uniformly north-northeast and over most of the area surveyed the radioactivity units consistently parallel this trend. In the Maryland portion of the area studied there is a remarkably good correlation of radioactivity with the geology. In Virginia the radioactivity units have the same general configuration and trend as the rocks, however, unit boundaries cannot everywhere be related to geologic contacts primarily because of the scarcity of geologic information. In the following discussion on detailed correlation of aeroradioactivity to geology most examples will be taken from the Maryland portion of the area where detailed geologic mapping at a scale of 1 in. equals 1 mile (1:62,500) permits more valid correlations.

Detailed geologic maps of the following counties in the Maryland Piedmont and Blue Ridge are available: Baltimore[23], Carroll[24], Frederick[25], Howard[26], Montgomery[27], and Washington[28]. The formations are described by Knopf and Jonas[29], Nickelsen[30], by Stose and Stose[31], and by Jonas[33].

4.2.1 Baltimore Gneiss

The Baltimore Gneiss, named for the excellent outcrops in and around the city of Baltimore, is of Precambrian age, and is considered the oldest rock of the Piedmont. Typically, the rock is a banded granitoid gneiss composed of quartz, the potash feldspar microcline, the soda lime feldspar oligoclase, and biotite. Other accessory minerals include hornblende, garnet, magnetite, and zircon. In places the formation contains hornblende gneiss, which contrasts strongly with the granite-like appearance of the rest of the gneiss. The Maryland portion of the area studied contains four large bodies of the gneiss in and around Baltimore. One is in the southwestern part of the city and there is one each to the north, northwest, and west of the city. Radioactivity over the gneiss is uniformly high, 600 to 800 cps, and the areas can be easily recognized on Plate 1. The two elliptical bodies of gneiss, one to the northwest of Baltimore traversing the regional strike and the other west of the city paralleling the strike, are beautifully delineated even on the small-scale generalized aeroradioactivity map (Fig. 3). The abrupt change to a higher radioactivity over the gneiss is present nearly everywhere at the contact of the Baltimore Gneiss with the surrounding Glenarm Series or gabbro. The detailed geology of the gneiss dome west of Baltimore is shown in Figure 7. Here the break to a higher

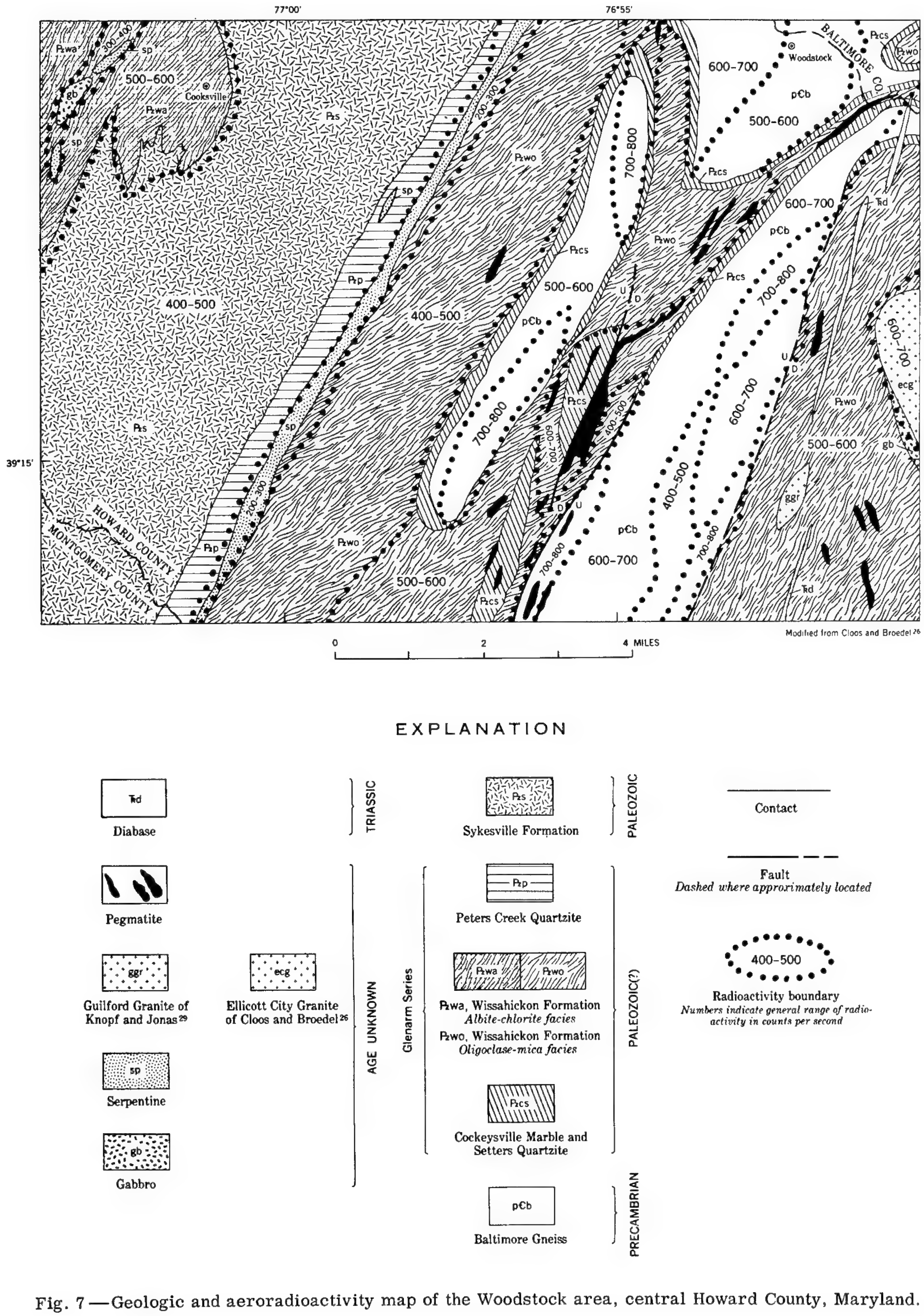


Fig. 7—Geologic and aeroradioactivity map of the Woodstock area, central Howard County, Maryland.

radioactivity over the gneiss follows the contact of the gneiss with the surrounding Glenarm Series. Radioactivity variations within the gneiss probably reflect the difference between the granitic and hornblende varieties.

A large body at the southern margin of the surveyed area in Virginia is classified as Baltimore Gneiss on the 1928 state geologic map[11]. On the 1963 map[12] it is called granite gneiss. Over about one half of this body the radioactivity is above 600 cps and locally reaches values up to 1200 cps. Over the other half of the body are many aeroradioactivity units with low values, mostly under 400 cps. Detailed mapping in this area will probably show lithologic variations in the gneiss which would account for the lower radioactivity.

4.2.2 Injection Complex

The basement rock of the western part of the Piedmont-Blue Ridge is an injection complex consisting of mica schist intruded by hornblende diorite, granodiorite and a biotite granite. This complex, considered Precambrian in age, is predominantly a granodiorite in Maryland where it underlies the Middletown Valley in western Frederick County between Catoctin Mountain and South Mountain. Figure 8 shows the geology and aeroradioactivity of the Middletown Valley. Radioactivity over the injection complex is low to moderate. The units vary from 300 to 600 cps and parallel the north-northeast geologic trend. The higher radioactivity is associated with zones of biotite granite gneiss which is higher in potash feldspar. The Catoctin Metabasalt, which flanks the injection complex, has a uniformly low radioactivity level, 100 to 300 cps, and at the contact of the two units there is a consistent abrupt change to the higher radioactivity of the injection complex.

In the Virginia portion of the area studied the rocks of the injection complex are not differentiated on the 1928 state geologic map[11] but are called Marshall Granite of Jonas[28], which includes other Precambrian rocks. On the 1963 geologic map of Virginia[12] the granite is termed the Marshall Formation. The Marshall Granite extends from the western edge of the area surveyed northeastward across Virginia to the Potomac River. Radioactivity over this area varies from 300 to 1100 cps. Southwest of the Potomac River almost to 39° 00' N. latitude, a distance of 20 miles, radioactivity varies from 300 to 600 cps, suggesting that the rocks may be a continuation southwestward of the types found in the Middletown Valley. Southwest of 39° 00' N. latitude radioactivity abruptly rises and displays some of the highest levels found in the area surveyed. Radioactivity is not uniform for the area contains many small north-northeast trending units with internal variation of 100 to 200 cps. Detailed geologic mapping here would probably show that the injection complex is equally as varied and that the radioactivity highs correspond to the biotite granite gneiss zones.

4.2.3 Glenarm Series

In the eastern Piedmont of both Maryland and Virginia the Glenarm Series is a conformable group of metamorphosed sedimentary

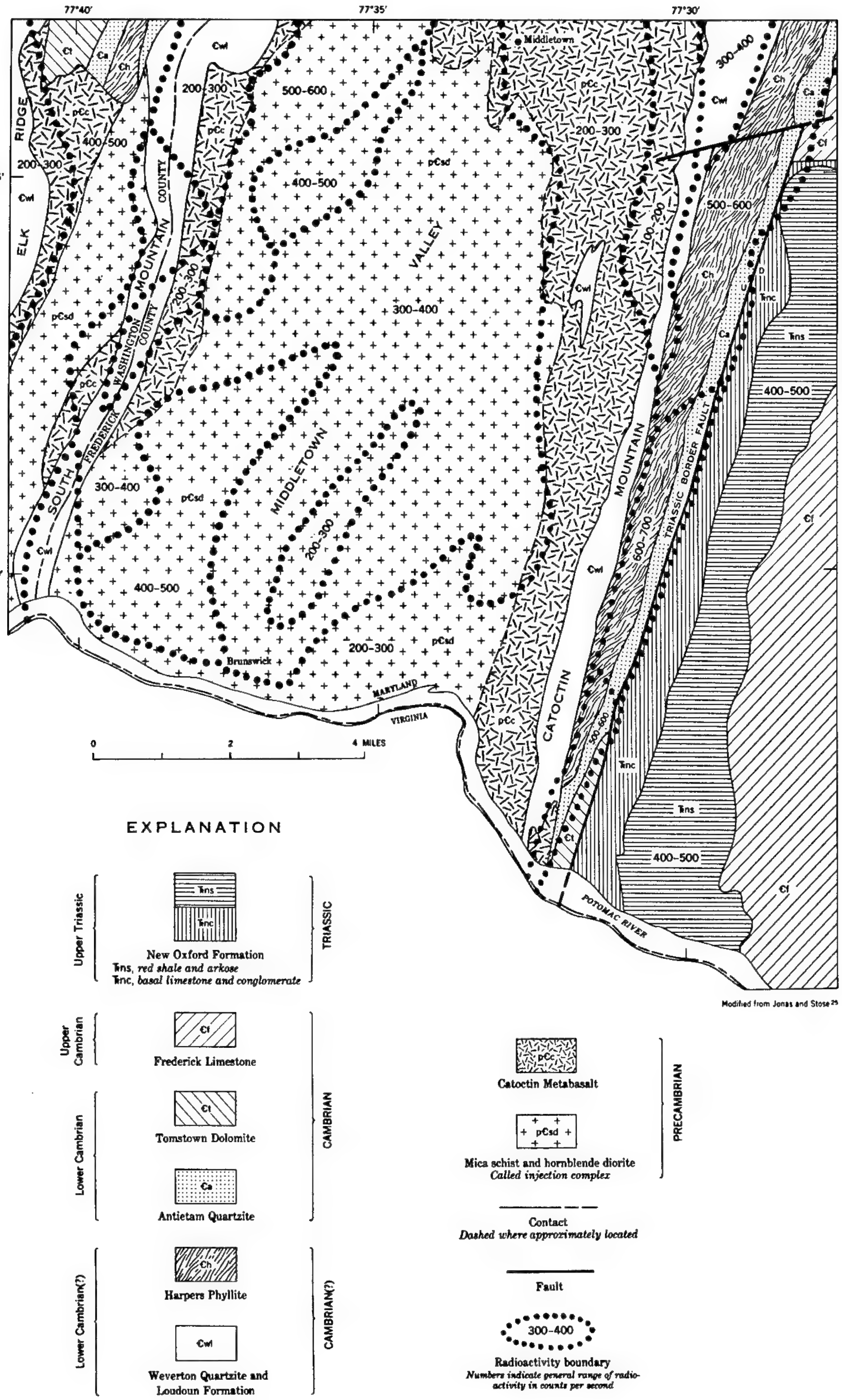


Fig. 8—Geologic and aeroradioactivity map of the Brunswick–Middletown area, Frederick and Washington Counties, Maryland.

rocks which unconformably overlie the Baltimore Gneiss. These rocks outcrop continuously over a width of 5 to 15 miles from Pennsylvania through Maryland and Virginia and constitute the principal rocks of the Piedmont province east of the Triassic Lowland. The age of the Glenarm is early Paleozoic(?).

The Setters Formation, a micaceous quartzite, is the oldest formation in the Glenarm Series. Overlying the Setters is the Cockeysville Marble. Since outcrops of these two formations are small they have been included with the Wissahickon on the generalized geologic map (unit Pzwcs,Fig. 4). The Wissahickon Formation forms an almost continuous band, 5 to 15 miles in width, along the eastern Piedmont in Maryland and Virginia. It is divided by Stose and Stose (Ref. 31, p. 56) into an eastern oligoclase-mica schist facies and a western albite-chlorite schist facies. Overlying the Wissahickon is the Peters Creek Quartzite, a variable sequence of interlayered quartzite, micaceous quartzite, and mica schist. The Sykesville Formation of post-Glenarm age earlier thought to be a granitic intrusive, is a coarse feldspathic, schistose quartzite and disruptive conglomerate of sedimentary origin which grades into the Peters Creek. The Ijamsville Phyllite, the westernmost unit of the Glenarm Series, is a chlorite-muscovite quartz phyllite thought to be equivalent in part to the Wissahickon Formation.

In summary, the Glenarm Series in the area surveyed consists mainly of schists and phyllites with varying assemblages of quartz, chlorite, muscovite, albite, and oligoclase. In Maryland, the radioactivity of the Glenarm Series is moderate with values ranging from 400 to 650 cps. Detailed mapping has delineated the several formations sufficiently so that comparisons in aeroradioactivity can be made. The Sykesville Formation has uniform values of 400 to 500 cps. The Wissahickon Formation and Peters Creek Quartzite range from 400 to 500 cps; however, much of the area of the western albite-chlorite phase of the Wissahickon has consistently higher values of 500 to 600 cps. The Ijamsville Phyllite is slightly higher with uniform values of 500 to 650 cps. North of Baltimore City is an area of Cockeysville Marble large enough to determine the radioactivity of the formation. Values range from 300 to 450 cps. The moderately uniform radioactivity of the Glenarm Series in Maryland is interrupted by north-northeast trending zones of strongly contrasting lower radioactivity (150 to 300 cps) over mafic intrusives (Figs. 7 and 9). At the contact of the Glenarm Series with granite and Baltimore Gneiss areas there is an abrupt rise in radioactivity to 600 to 850 cps (Fig. 7).

In the Virginia portion of the area surveyed the Wissahickon Formation and Peters Creek Quartzite have lower values of 200 to 600 cps. In contrast to the uniform levels in Maryland, radioactivity over these formations in Virginia is broken into many well defined elongated units which parallel the north-northeast geologic trend. There are many well-developed lows of 200 to 300 cps and 300 to 400 cps. In the Fairfax Quadrangle, Va., detailed (1 in. equals one mile) mapping by Bennison and Milton[32] has differentiated extensive areas of metabasalt within the area earlier mapped as Wissahickon Formation. Radioactivity over this metabasalt is 200 to 400 cps contrasting with the higher values over the schist. It is very probable that further detailed mapping in Virginia will

delineate other mafic bodies. A body of granitized Wissahickon at the southern margin of the area surveyed has many radioactivity units varying from 200 to 900 cps. Highest values are probably over the more granitic zones.

4.2.4 Catoctin Metabasalt and other Metavolcanics

The Catoctin Metabasalt of Precambrian age consists of a series of metamorphosed flows and tuffs, which make up a large part of the western Piedmont in Maryland and Virginia where the formation crops out continuously along two broad north-northeast trending belts. The Catoctin Metabasalt rests unconformably on the hornblende diorite injection complex of the western Piedmont. Typically the Catoctin is a dense fine-grained green-schist composed of hornblende, epidote, chlorite, feldspar, and some quartz. The radioactivity of the Catoctin is usually low, from 100 to 300 cps. Outside of the Coastal Plain the Catoctin Metabasalt accounts for the largest areas of low radioactivity in the area surveyed. The broad north-northeast trending belt of low radioactivity extending diagonally through Point of Rocks, Md., and Warrenton and Culpepper, Va. (Pl. 1 and Fig. 3), defines almost perfectly a zone of Catoctin Metabasalt and clastic deposits of the Chilhowee Group. Low radioactivity along this belt contrasts sharply with the higher radioactivity (300 to 1100 cps) over the granite and injection complex to the west and with the higher radioactivity (300 to 600 cps) over the Triassic on the east. In Figure 8, which shows the detailed geology of the Brunswick-Middletown area in Frederick and Washington Counties, Md., the low radioactivity on each side of Middletown Valley very excellently defines the contact between the Catoctin and the injection complex.

West of the injection complex in Virginia and just east of the Blue Ridge, a second belt of Catoctin Metabasalt traverses the area surveyed. Radioactivity values over this belt, however, vary from 100 to 700 cps. In contrast to the uniform radioactivity (100 to 300 cps) over the eastern belt of Catoctin, the radioactivity here is broken into many small units of different values indicating that the rocks vary markedly in composition. Detailed mapping will probably show this.

Eastern Frederick County, Md., north and west of Hyattstown contains a large area of metavolcanics of different types. Radioactivity here is broken into several units which vary from 200 to 600 cps contrasting nicely with the uniform 500 to 600 cps radioactivity of the Ijamsville Phyllite to the east. In the areas of metavolcanics, low values of 200 to 300 cps are found over the metabasalt and higher radioactivity of 400 to 600 cps over metarhyolite and meta-andesite.

4.2.5 Granitic Rocks

Many kinds of granitic rocks have been intruded into the metamorphic sequence of the Piedmont province. Most of these intrusives have been mapped and described as granites but they

vary markedly in type and mineral composition. Included in the granitic group are igneous rocks having an even granular texture and containing quartz, feldspar, and dark colored minerals, generally biotite and hornblende. Petrologists generally restrict the term granite to rocks in which feldspar is dominantly of the potash variety (orthoclase and microcline). As the percentage of soda-lime feldspar (plagioclase) increases with respect to potash feldspar, different terminology is used. In a quartz monzonite the percentage of plagioclase is appreciable. If plagioclase greatly exceeds orthoclase the rock is termed a granodiorite. The name quartz diorite is given to a rock whose feldspar is dominantly plagioclase.

In Maryland the granitic rocks have been mapped and described in detail so that it is possible to make some valid correlations between the type of granitic rock and associated aeroradioactivity. As would be expected, the highest levels are found over true granites in which the feldspar is predominantly potassic. In Figure 7, the detailed geologic and aeroradioactivity map of an area in Howard County shows a small portion of the Ellicott City Granite of Knopf and Jonas[29], mineralogically a quartz monzonite which here intrudes the Wissahickon Formation. Radioactivity over the Ellicott City is 600 to 700 cps and the Wissahickon is uniformly 500 to 600 cps. The boundary between the two radioactivity units coincides with the contact between the two formations.

On the state geologic map of Virginia (both the 1928[11] and 1963[12] editions) several extensive areas are mapped as granite. Radioactivity over these areas varies from 200 to 1500 cps and in each area there are some of the highest levels of radioactivity encountered in the entire survey. There are also extensive zones of low to moderate radioactivity. The granitic areas in Virginia include true granite and various related rocks containing lesser amounts of potash feldspar. Detailed mapping in Virginia would probably make possible the same correlation of radioactivity to granitic rock type as can be done in Maryland.

4.2.6 Mafic Intrusive Rocks

Mafic rocks are dark colored igneous rocks composed dominantly of ferromagnesian silicate minerals. Plagioclase is the normal feldspar. The Piedmont portion of the area surveyed contains many varieties of mafic intrusives such as diabase, gabbro, metagabbro, pyroxenite, peridotite, and the alteration product serpentine. These rocks all have uniformly low radioactivity of 100 to 350 cps.

Detailed mapping in Maryland has delineated numerous mafic bodies of varying size. Their uniformly low radioactivity makes them stand out in strong contrast to the surrounding Piedmont. On Plate 1 the numerous north-northeast striking elongated areas of low radioactivity under 300 cps outline the mafic bodies almost perfectly. A large gabbro mass covering all of western Baltimore City and the western suburbs has a northeast-southwest extent of 15 miles. Over the entire area radioactivity is remarkably uniform (200 to 300 cps). In the area of the gabbro, one cannot define the Coastal Plain margin because both the gabbro and Cretaceous rocks of the Coastal

Plain in the Baltimore area have nearly identical radioactivity. On the west, however, the contact of the Baltimore gabbro is strikingly delineated by radioactivity and stands out markedly from the higher levels of the Wissahickon Formation (400 to 500 cps) and the Ellicott City Granite (600 to 700 cps).

A serpentine dike striking north-northeast extends a continuous distance of 18 miles from Carroll County across Howard County into Montgomery County. Over most of its length it is 1/8 to 1/4 mile wide, yet each flight profile shows a marked low over the serpentine. A portion of this dike is shown in Figure 7. The dike is at the contact of the Wissahickon Formation with the Sykesville Formation to the west. Both of these formations have a radioactivity of 400 to 500 cps whereas the level over the dike is 200 to 300 cps. The full extent of this dike can be seen on Plate 1.

Southwestern Montgomery County, south and west of Gaithersburg and Rockville, has several elongate bodies of serpentine and gabbro. Figure 9, the detailed geologic and radioactivity map of the Gaithersburg area in Montgomery County, shows four of these intrusions. All of these areas are nicely delineated by the low radioactivity which contrasts with the higher level of 500 to 600 cps of the surrounding Wissahickon Formation. Figure 9 also shows an intrusive body of Triassic diabase in the northwest corner, in contact with Ijamsville Phyllite, Wissahickon Formation, and the New Oxford Formation of Triassic age. Radioactivity over the diabase is 200 to 350 cps whereas over the surrounding rocks the levels are 400 to 600 cps.

4.2.7 Chilhowee Group

The Chilhowee Group of Early Cambrian and Early Cambrian(?) age consists of a variety of clastic sedimentary rocks and is divided into four formations. The oldest is the Loudoun Formation, a tuffaceous phyllite grading upward to an arkosic quartzite, containing abundant detrital potash feldspar (microcline and orthoclase). Overlying the Loudoun Formation is the Weverton Quartzite, composed mostly of massive, resistant, vitreous, quartzite beds. Next youngest is the Harpers Phyllite, a phyllite or micaceous slate containing a few quartzose layers. This formation grades upward into a micaceous schist with abundant detrital potash feldspar. At the top of the group is the Antietam Quartzite, a massive even-grained quartzite, for the most part very pure, containing about 90 percent quartz. Some layers are sericitic containing 60 percent quartz and up to 25 percent potash feldspar.

Quartzite units of the Chilhowee Group, particularily the Antietam and Weverton, are the principal resistant ridge-making formations of the Blue Ridge province. Catoctin Mountain, South Mountain, and the Blue Ridge (Elk Ridge in Maryland) are composed mostly of Weverton Quartzite. In the Piedmont province many lower ridges are underlain by resistant units of the Chilhowee Group.

The radioactivity units over the formations of the Chilhowee Group are in narrow elongate north-northeast trending bands which coincide beautifully with the geologic pattern. Contrasting low radioactivity is associated with the pure quartzites. On Plate 1

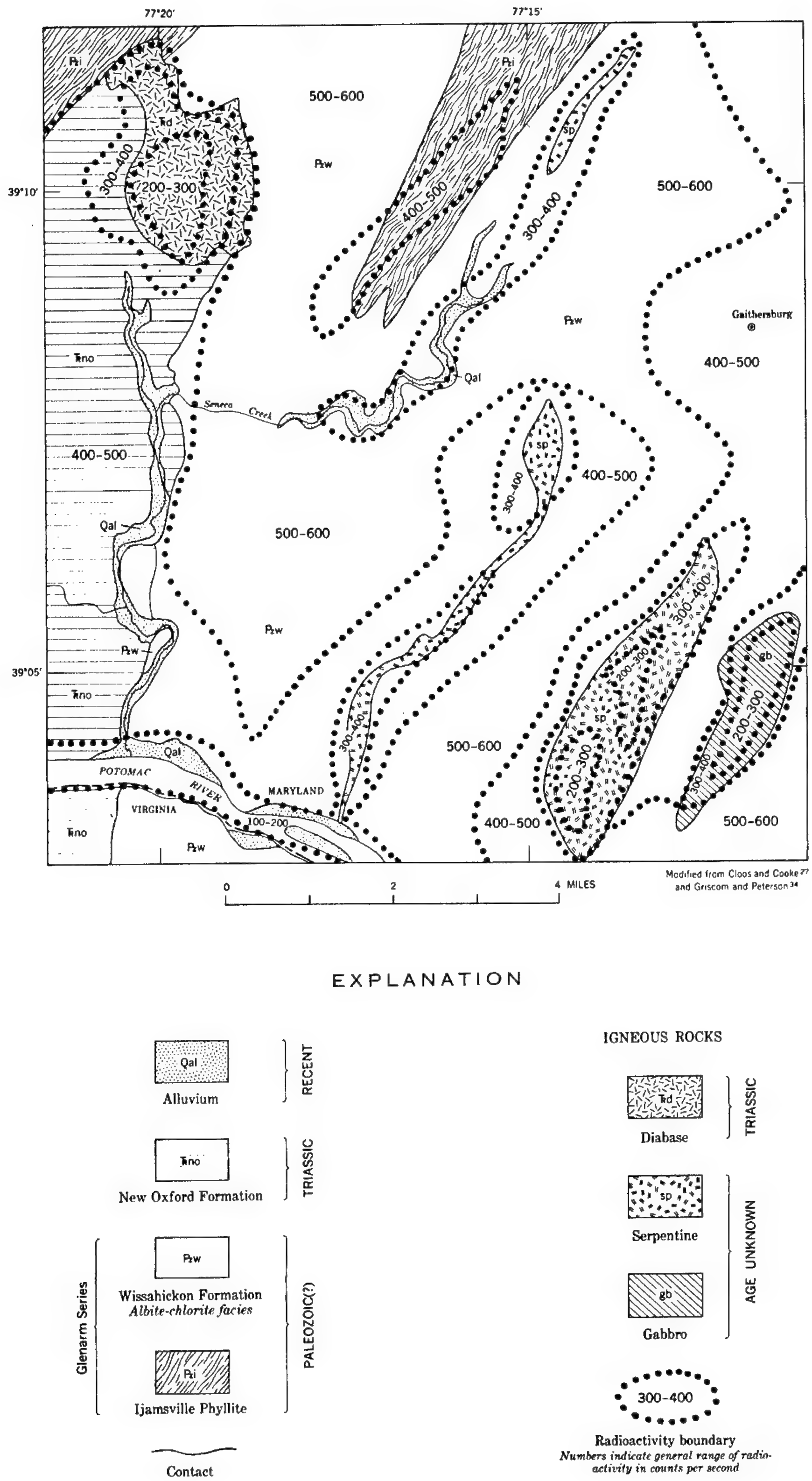


Fig. 9—Geologic and aeroradioactivity map of the Gaithersburg area, southwestern Montgomery County, Maryland.

the Blue Ridge, Catoctin Mountain, Short Hill, and South Mountain are well defined by the several north-northeast trending narrow belts of low radioactivity (100 to 300 cps) in the northwestern corner of the surveyed area. These lows are developed for the most part on the Weverton Quartzite and can be seen also in Figure 8. In southeastern Frederick County is Sugarloaf Mountain, which rises about 800 ft above the level of the Piedmont uplands. This topographic high is capped by the Sugarloaf Mountain Quartzite, a massive, resistant, white quartzite, lithologically similar to the Weverton Quartzite of Catoctin Mountain to the west. On Plate 1 Sugarloaf Mountain can be readily located by the nearly circular area of very low radioactivity (100 to 200 cps) which contrasts strongly with the higher levels of the surrounding Piedmont.

Over the other formations of the Chilhowee Group (Loudoun, Harpers, and Antietan), radioactivity varies from 200 cps to as much as 800 cps in some places. For example, just east of Frederick, Md., there is a group of linear hills extending from the Potomac River to the northern edge of the area studied, a distance of 15 miles. These hills, developed on rocks which have been mapped as Antietam Quartzite exhibit moderate to high radioactivity (600 to 800 cps), which coincides nearly with the outcrops. It is very probable that the higher radioactivity values are associated with a more argillaceous facies lithologically different from the Antietam to the west.

4.2.8 Frederick Valley and Triassic Lowlands

The Frederick Valley, a lowland in the western part of the Piedmont province, is at an elevation of 300 ft, about 400 ft below the general level of the Piedmont upland. The valley averages 4 to 6 miles in width and extends from the Potomac River north for a distance of 25 miles. The area is underlain by the Frederick Limestone of Late Cambrian age and the Grove Limestone of Early Ordovician age. The Frederick Limestone is a thin-bedded, slabby, impure argillaceous limestone which underlies most of the valley. Narrow outcrops of Grove Limestone, a very pure high calcium limestone, occur in several synclinal folds within the Frederick Limestone. Radioactivity over the Frederick Limestone is uniformly 400 to 500 cps, whereas the levels over the Grove Limestone, the purer limestone, are 300 to 400 cps.

The Triassic Lowland in the western Piedmont is developed on an almost continuous belt of red shale and sandstone of Triassic age, which extends from New Jersey southward through Pennsylvania and Maryland into central Virginia. In the vicinity of Frederick, Md., the north-south continuity of the Triassic is interrupted by the limestones of the Frederick Valley. The Triassic rocks are known as the Newark Group, which consists of a lower red sandstone unit, the New Oxford Formation in Maryland and the Manassas Sandstone of Roberts[35] in Virginia; and an upper shale unit, the Gettysburg Shale in Maryland and the Bull Run Shales of Roberts[35] in Virginia. The beds of the Newark Group dip 10° to 20° northwest, and are cut off on the west by the Triassic border fault. Radioactivity over the Triassic Lowland is low to moderate (200 to 600 cps). Where

detailed mapping has been done in Maryland it is possible to make some correlations of radioactivity with formations of the Triassic. In western Montgomery County (Fig. 9) radioactivity over the diabase is low, 200 to 400 cps, and rises abruptly to 400 to 500 cps at the contact of the diabase with the sandstone of the New Oxford Formation. Farther west in Montgomery County, just west of the area covered by Figure 9, values over the Gettysburg Shale are 500 to 600 cps.

4.3 Appalachian Valley

The Appalachian Valley, referred to in Maryland as the Hagerstown Valley and in Virginia as the Shenandoah Valley, is a broad, gently undulating lowland with local ridges and hills from 500 to 600 ft in elevation. It is underlain by a thick sequence of northeast striking Cambrian and Ordovician shale, limestone, and dolomite, which were folded and faulted and subsequently reduced by erosion to form the present lowland. In the Washington, D. C. study area, all the area westward from the western foot of the Blue Ridge or South Mountain is included in the Appalachian Valley. The distribution of the Appalachian Valley formations is mapped in detail at the scale of 1:62,500 on the geologic map for Jefferson, Berkeley, and Morgan Counties, W. Va.[36]. Formations are described in the report covering these three counties[37].

Excellently defined linear radioactivity units parallel the strike of the rocks throughout the Appalachian Valley. Some of the best correlations of aeroradioactivity to geology in the area surveyed are found in this region. In general, low radioactivity is found over the relatively pure limestones and dolomites, and higher values over the shales and less pure limestones. Bates[38], in a similar ARMS-I study of the Oak Ridge area, Tenn., observed the same excellent definition of geology units by radioactivity in the Appalachian Valley and Ridge province, where he found that some units could be traced for a distance of 100 miles.

The Tomstown Dolomite and the Waynesboro Formation immediately overlie the Harpers Phyllite and Antietam Sandstone and are exposed along the eastern edge of the Appalachian Valley for a width of $1\frac{1}{2}$ to 3 miles. The Tomstown is chiefly a medium bedded, blue-gray dolomite, whereas the Waynesboro Formation is a miscellany of shale, argillaceous limestone, impure sandstone, and dolomite. Lithologies change along the strike and across the beds. The radioactivity over the Tomstown and Waynesboro ranges from 200 to 800 cps, reflecting these facies changes. The area is broken up by numerous small radioactivity units of 100 cps intervals both across and along the strike. Some of the very low (200 to 400 cps) values may be over the sandstone facies of the Waynesboro or may be due to the presence of slope wash from the low radioactivity sandstones and quartzites of the Blue Ridge to the east.

The Elbrook Limestone of Cambrian age lies immediately above the Waynesboro and crops out over a width of $3\frac{1}{2}$ to 5 miles along the Appalachian Valley. It resembles the Waynesboro in that it is composed of a variety of rock types: massive pure limestone, shale, and argillaceous sandstone. The Elbrook Limestone has the highest

radioactivity values of all the formations of the Appalachian Valley in the Washington, D. C. area (500 to 800 cps), with much of the area above 600 cps. The radioactivity over the Elbrook is similar to that over the Waynesboro in that it is broken into distinct units of 100 cps which reflects the different rock types. The absence of radioactivity values less than 500 cps is probably due to the fact that the Elbrook contains no sandstone beds as the Waynesboro does.

The Conococheague Limestone of Cambrian age and the Beekmantown, Stones River, and Chambersburg Limestones of Ordovician age crop out in northeast-trending bands to the west of the Elbrook. This group of four formations consists of massive beds of uniformly pure limestone and dolomite. Except for a few argillaceous limestone beds in the lower part of the Conococheague and near the top of the Chambersburg, these formations are lacking in shales. The uniform radioactivity value of 400 to 500 cps reflects the homogeneity of the calcareous rocks and stands out in contrast to the mixture of radioactivity units over the Elbrook Limestone and the Waynesboro Formation. The contact between the two limestones (Chambersburg-Stones River) and the Martinsburg Shale is well defined by the higher radioactivity of 500 to 600 cps over the Martinsburg.

The Martinsburg Shale has a few argillaceous limestones near the base but otherwise consists of rhythmically interbedded black shale and graywacke. The radioactivity values are consistently from 500 to 600 cps and show the uniform character of the formation.

5. SUMMARY

The natural radioactivity of the Washington, D. C. survey area ranges from 100 to 1500 cps and all changes in level are due to the varying radionuclide content of the rocks and soils. Low radioactivity levels (100 to 400 cps) are associated with sandstone, quartzite, mafic rocks, and some limestones. Intermediate levels (400 to 600 cps) are over marl, shale, gneiss, schist, and phyllite. The highest radioactivity (more than 600 cps) is found over granite, some gneiss, and some shale.

The linear pattern of radioactivity units throughout the area shows a remarkable correlation with the north-northeast strike of the geologic units. The area is an excellent one to demonstrate the relation between aeroradioactivity and geology. There are many distinct radioactivity breaks of considerable extent which can be related directly to known geologic contacts. The correlation of radioactivity with geology is particularly good in the Piedmont province of Maryland where there are good detailed geologic maps at a scale of 1:62,500. It is possible that more detailed geologic mapping in the state of Virginia would show the same excellent association of radioactivity boundaries to geologic contacts.

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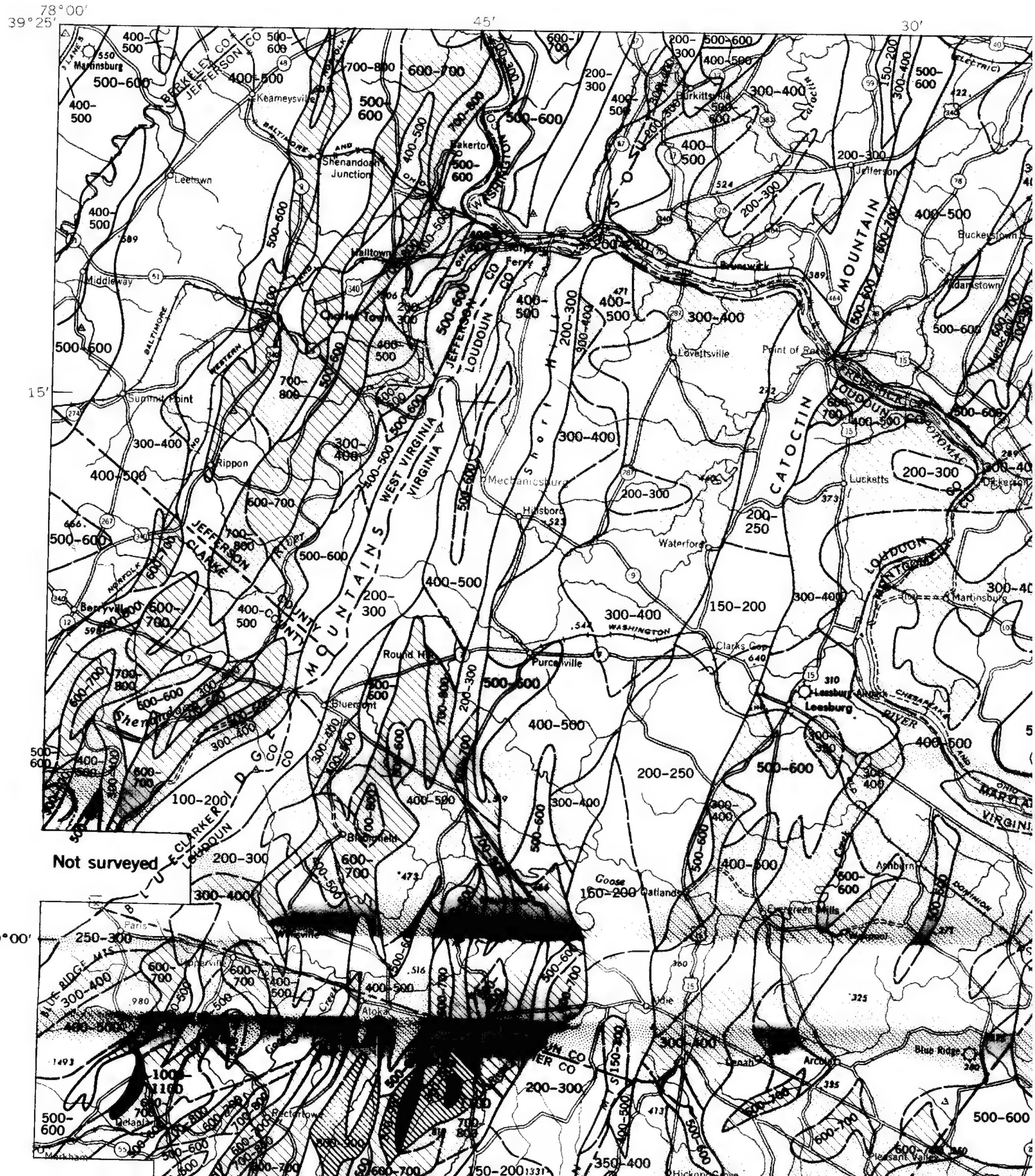
DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY



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DIVISION OF BIOLOGY
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PREPARED IN COOPERATION WITH

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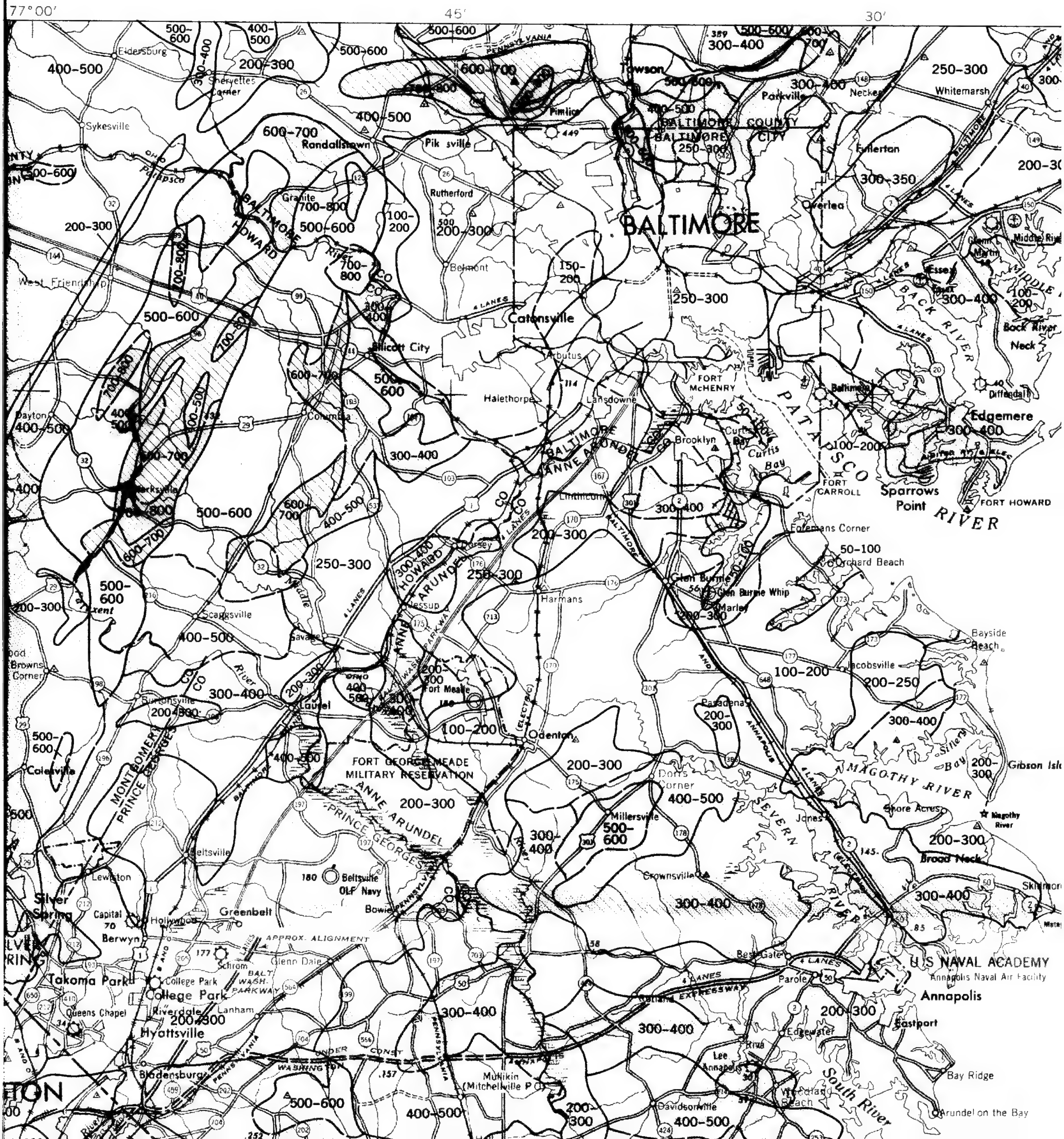
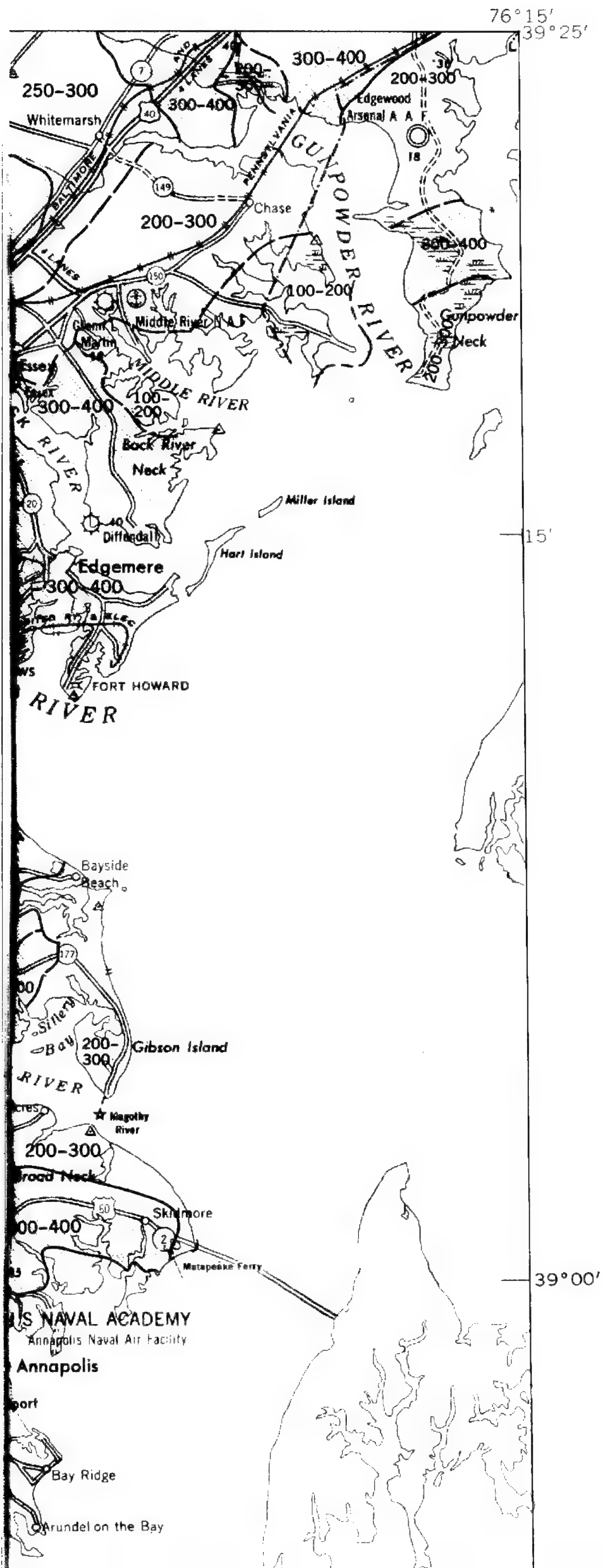


AEC-CEX 59.4.17
GEOPHYSICAL INVESTIGATIONS
MAP GP-475



EXPLANATION

300-400

Radioactivity boundary

Solid where well defined, dashed where not well defined. Numbers indicate general range of radioactivity levels in counts per second

Over 1000

900-1000

800-900

700-800

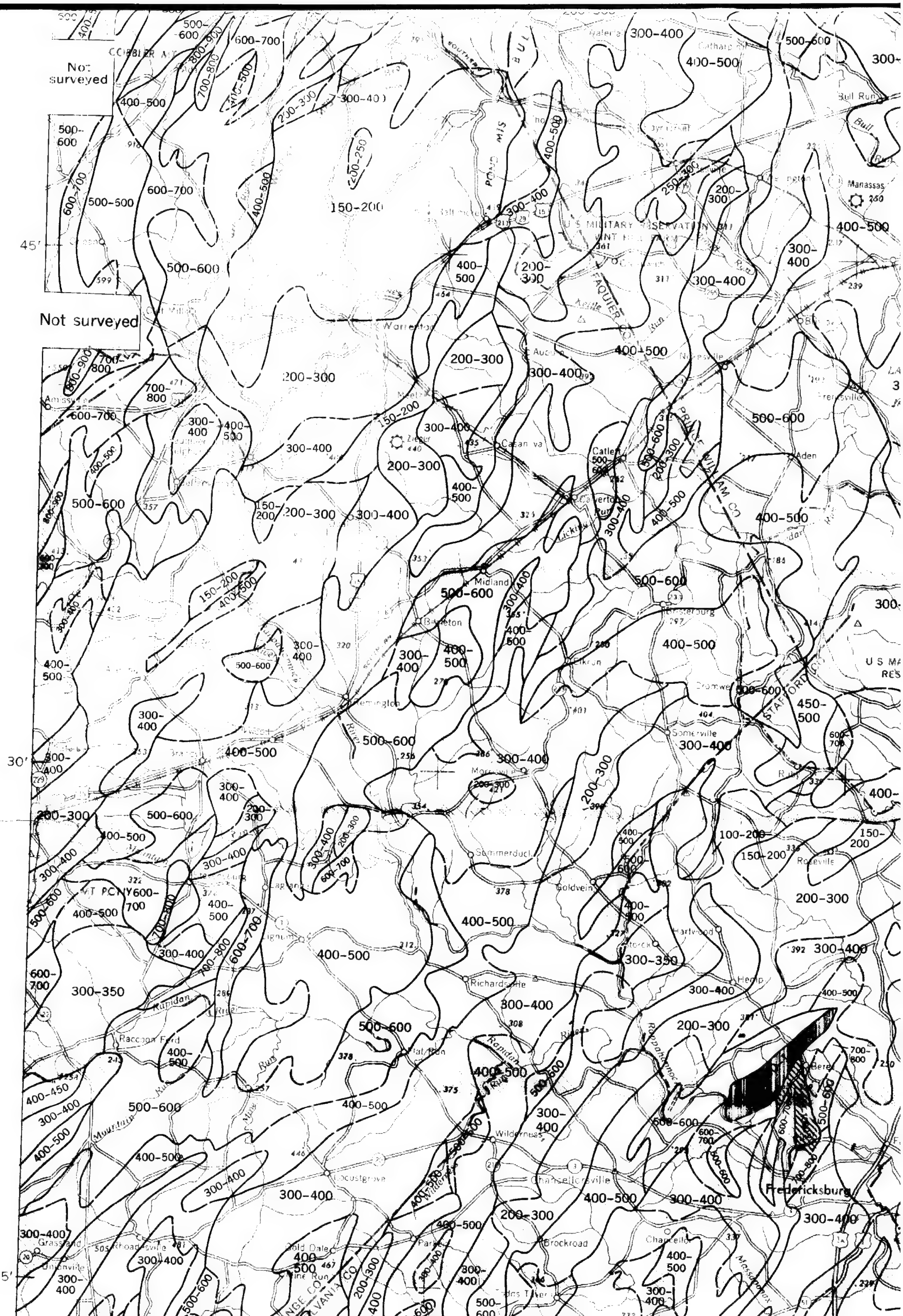
600-700

500-600

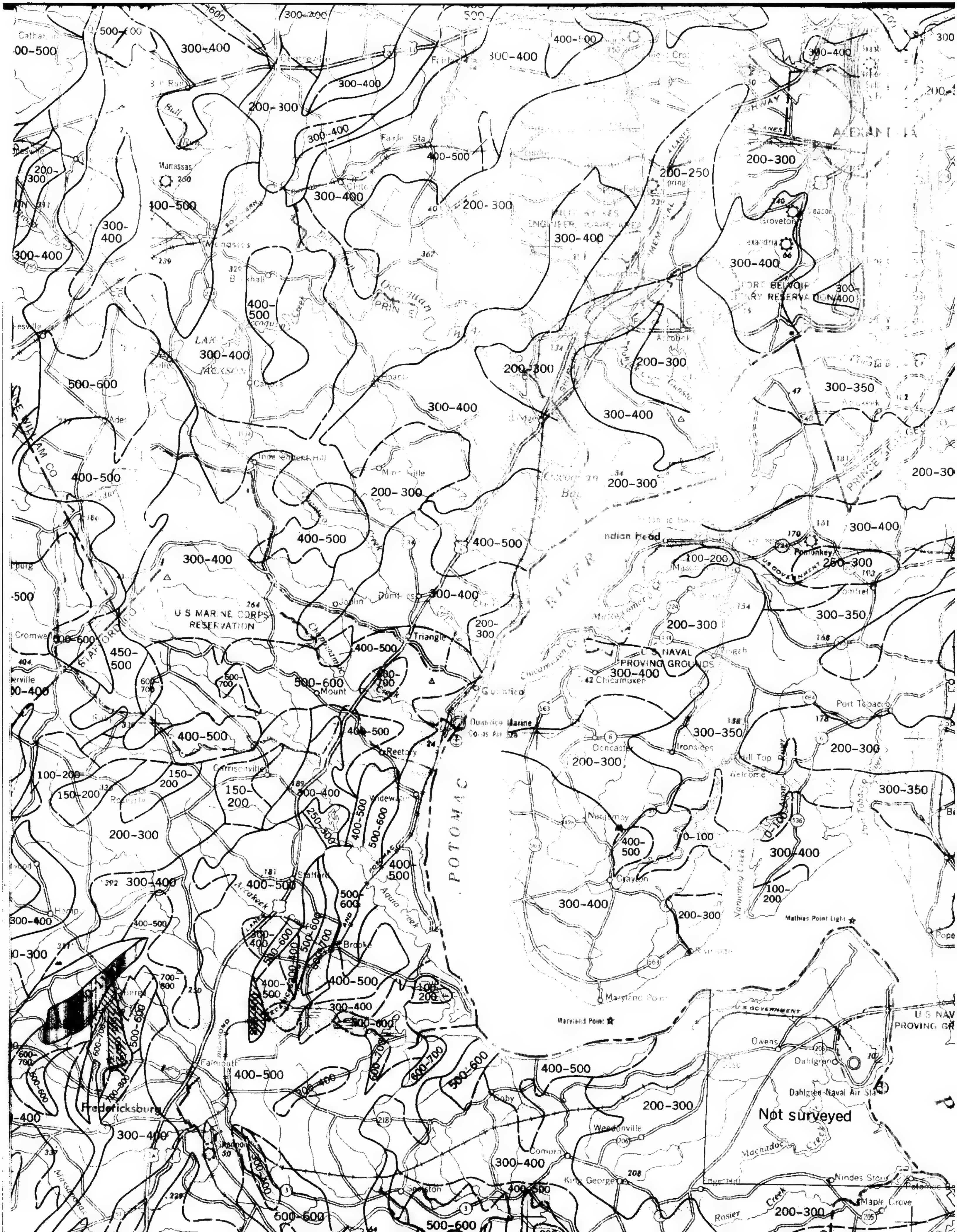
400-500

300-400

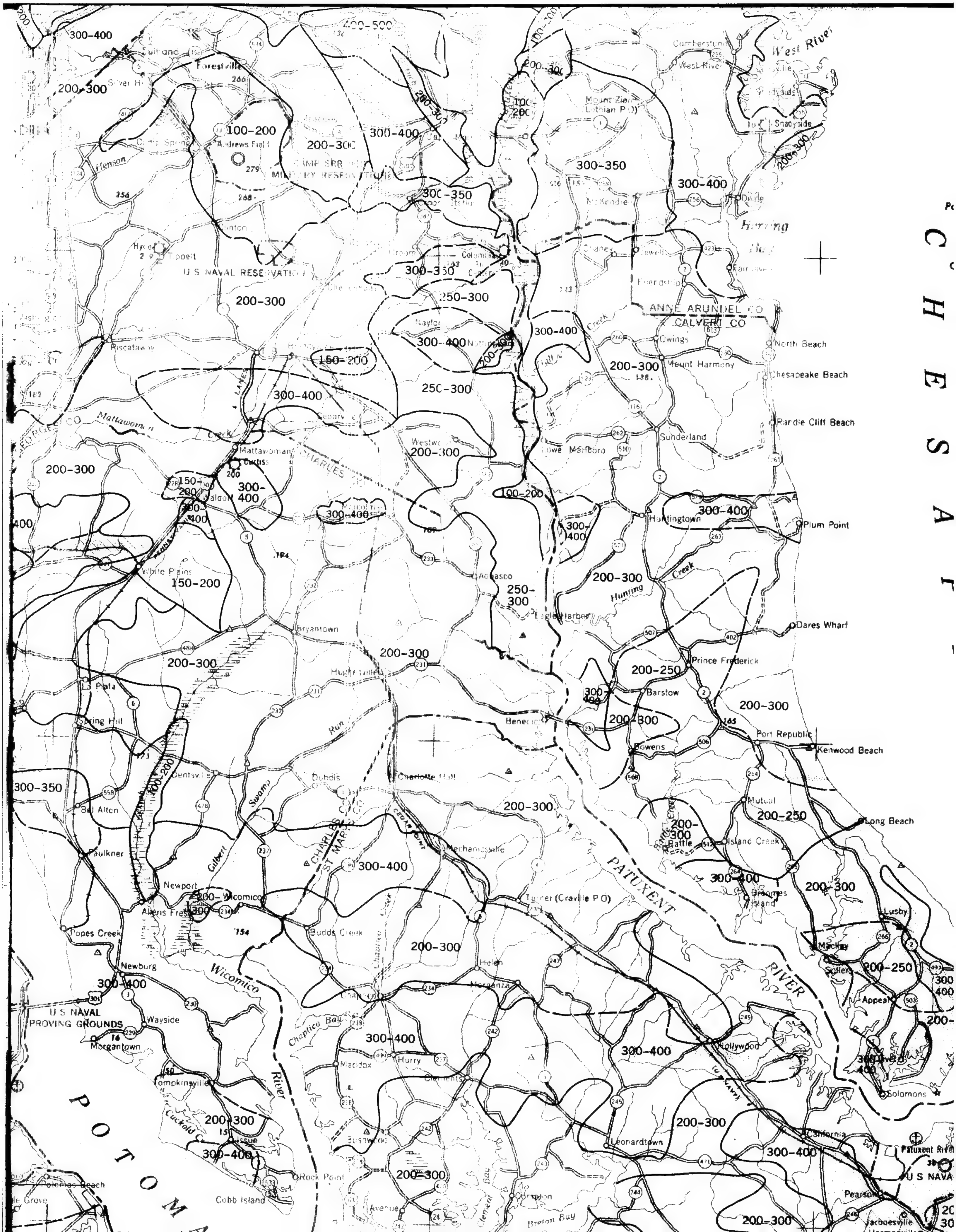
200-300



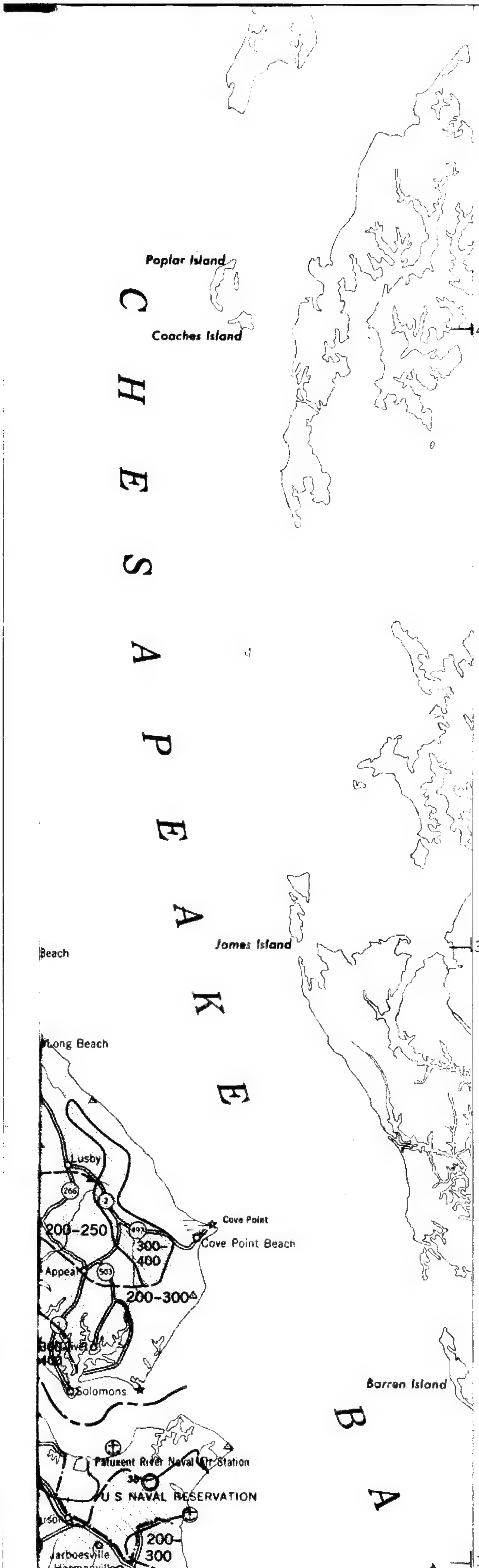
Not surveyed
Not surveyed
45'
30'
15'
Warrenton
Manassas
Bull Run
U S MILITARY RESERVATION
FAUQUIER CO
PRINCE WILLIAM CO
STAFFORD CO
Nokesville
Catlett
Calverton
Midland
Bealeton
Remington
Elkrun
Somerville
Aden
Morrisville
Sommerduck
Goldvein
Hartwood
Roseville
Richardsville
Raccoon Ford
Rapidan
Wilderness
Chancellorsville
Locustgrove
Brockroad
Chancellor
Grassland
Fredericksburg



300-400
500-600
300-400
200-300
300-400
200-300
300-400
Manassas
400-500
300-400
300-400
400-500
300-400
200-250
200-300
200-300
300-400
Groveton
FORT BELVOIR
300-400
400-500
300-400
500-600
200-300
200-300
300-350
300-400
300-400
400-500
200-300
200-300
Occoquan Bay
400-500
400-500
Indian Head
300-400
300-400
100-200
250-300
US GOVERNMENT
300-400
Dumfries
RIVER
U S MARINE CORPS RESERVATION
200-300
300-350
Triangle
200-300
Cromwell
500-600
STAFFORD
450-500
400-500
U S NAVAL PROVING GROUNDS
300-400
500-600
Chicamuxen
Quantico
Quantico Marine Corps Air Sta
Port Tobacco
400-500
400-500
300-350
Doncaster
Ironsides
200-300
200-300
Hill Top
100-200
150-200
150-200
150-200
Garrisonville
300-400
300-350
250-300
400-500
500-600
POTOMAC
Nanjemoy
400-500
0-100
0-100
200-300
400-500
300-400
400-500
Stafford
500-600
Grayton
100-200
300-400
300-400
200-300
Mathias Point Light
300-400
500-600
Brooke
400-500
400-500
100-200
300-400
500-600
Maryland Point
Maryland Point
U S GOVERNMENT
U S NAVAL PROVING GROUNDS
600-700
500-600
600-700
Falmouth
400-500
600-700
500-600
400-500
Owens
Dahlgren
Dahlgren Naval Air Sta
Fredericksburg
300-400
200-300
Not surveyed
300-400
Weedonville
Comorn
300-400
King George
Machadoc Creek
Nindes Store
Sealston
400-500
Rosier Creek
Maple Grove
200-300
500-600
500-600



300-400
400-500
West River
Forestville
200-300
100-200
Andrews Field
200-300
300-400
CAMP SPRINGS MILITARY RESERVATION
100-200
Mount Zion
Lothian P.O.
Cumberstone
Shadyside
300-350
300-400
300-350
Henson
Clinton
Tippett
U S NAVAL RESERVATION
McKendree
Herring Bay
C H E S A P
300-350
250-300
200-300
Friendship
ANNE ARUNDEL CO
CALVERT CO
Naylor
300-400
Nottingham
300-400
Owings
North Beach
Piscataway
150-200
200-300
Mount Harmony
Chesapeake Beach
300-400
250-300
Mattawoman Creek
Pardle Cliff Beach
Westwood
200-300
Sunderland
Lower Marlboro
Mattawoman
CHARLES CO
200-300
150-200
300-400
Waldorf
300-400
100-200
300-400
Huntingtown
300-400
Plum Point
300-400
White Plains
150-200
Aquasco
250-300
200-300
Hunting Creek
Eagle Harbor
Bryantown
Dares Wharf
200-300
200-300
Hughesville
200-250
Prince Frederick
La Plata
300-400
Barstow
200-300
Spring Hill
Run
Benedict
200-300
Port Republic
Kenwood Beach
Bowens
100-200
300-350
Dentsville
Dubois
Charlotte Hall
Swamp
200-300
Mutual
Bel Alton
200-250
Long Beach
Battle Creek
200-300
Battle
Island Creek
Mechanicsville
Paulkner
Gilbert
CHARLES CO
ST MARYS CO
300-400
PATUXENT
300-400
Broomes Island
200-300
Newport
300-Wicomico
300
Allens Fresh
Turner (Cravlie P.O.)
Lusby
Popes Creek
Budds Creek
200-300
Mackall
Newburg
Helen
Solomons
200-250
300-400
Wicomico
300-400
RIVER
Morganza
Appeal
U S NAVAL PROVING GROUNDS
Wayside
Chaptico Bay
300-400
Morgantown
Hollywood
300-400
Maddox
Hurry
Clements
Tompkinsville
River
POTOMAC
Cuckold
200-300
200-300
Leonardtown
California
Issue
300-400
300-400
Patuxent River
U S NAVAL
Rock Point
200-300
Potomac Beach
Cobb Island
Compton
Pearson
Avenue
Breton Bay
200-300
Jarboesville



0-100

Radioactivity units having ranges of 100 counts per second. Locally subdivided into units having range of 50 counts per second

EXPLANATORY TEXT

The survey was made with scintillation detection equipment (Davis and Reinhardt, 1957, 1962) installed in a twin-engine aircraft. Parallel east-west flight traverses spaced at one-mile intervals were flown at a nominal altitude of 500 feet above the ground. The flight path of the aircraft was recorded by a gyro-stabilized continuous-strip-film camera. The radioactivity data were compensated for deviations from the 500-foot surveying altitude, and for the cosmic-ray component.

The effective area of response of the scintillation equipment at an altitude of 500 feet is that encompassed by a circle approximately 1,000 feet in diameter, and the radioactivity recorded is the average radioactivity of that area. The scintillation equipment records only pulses from gamma radiation with energies greater than 50 kev (thousand electron volts). A cesium-137 source is used during periodic calibrations to assure uniformity of equipment response.

The gamma-ray flux at 500 feet above the ground has three principal sources: cosmic radiation, radionuclides in the air (mostly radon daughter products), and radionuclides in the surficial layer of the ground. The cosmic component is determined twice daily by calibrations at 2,000 feet above the ground, and is removed from the radioactivity data.

The component due to radionuclides in the air at 500 feet above the ground is difficult to evaluate. It is affected by meteorological conditions, and a tenfold change in radon concentration is not unusual under conditions of extreme temperature inversion. However, if such conditions are avoided, the air component may be considered to be fairly uniform on a given day in a particular area, and will not mask the differences in radioactivity levels that reflect changes in the ground component.

The ground component comes from approximately the upper few inches of the ground.

0-100

ty units having ranges of 100 counts per second. Locally
vided into units having range of 50 counts per second

EXPLANATORY TEXT

survey was made with scintillation de-
equipment (Davis and Reinhardt, 1957,
stalled in a twin-engine aircraft. Par-
st-west flight traverses spaced at one-
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500 feet above the ground. The flight
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ed continuous-strip-film camera. The
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from the 500-foot surveying altitude,
the cosmic-ray component.

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ses from gamma radiation with ener-
ater than 50 kev (thousand electron
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n is not unusual under conditions
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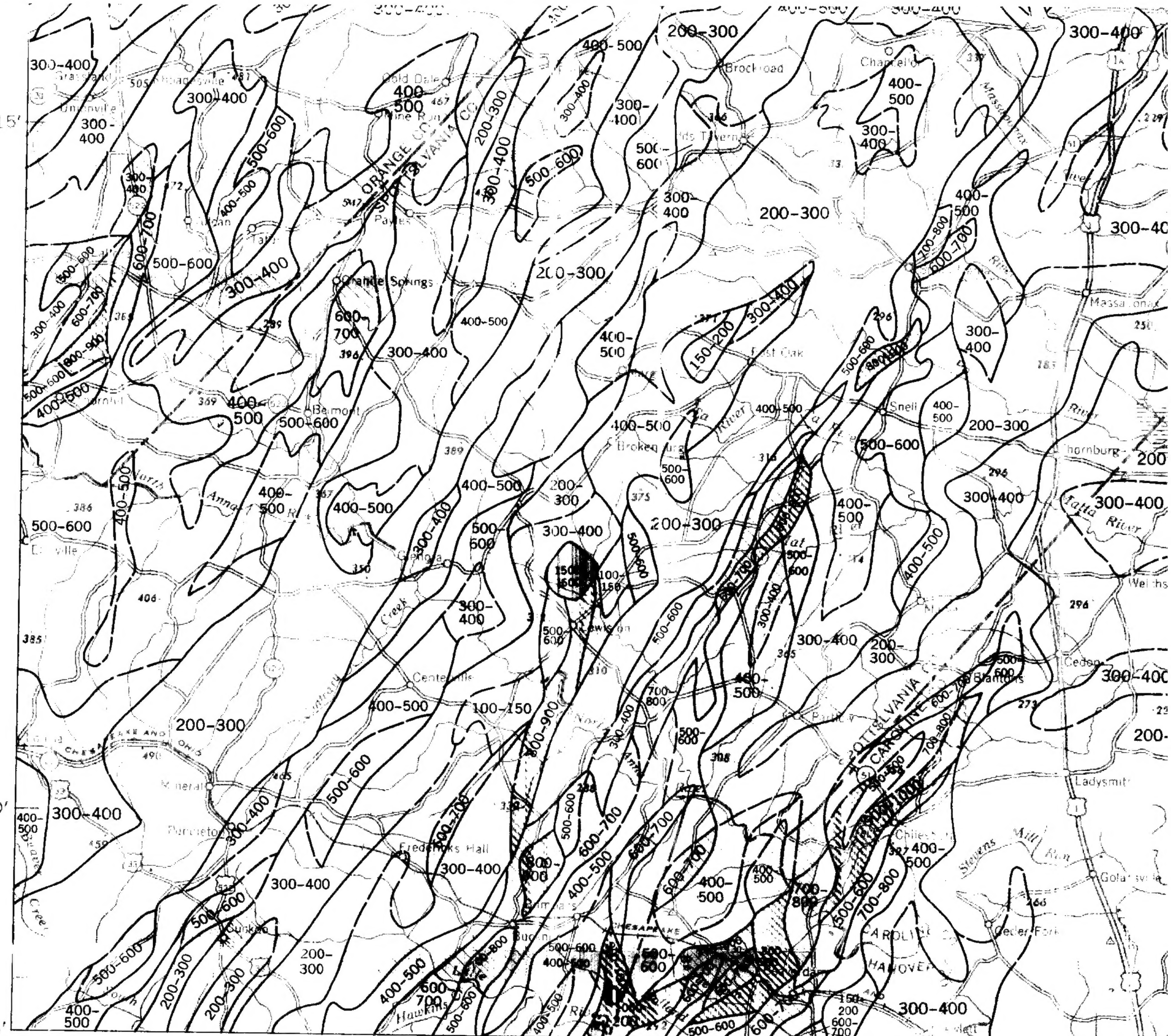


Base from Army Map Service 1:250,000 series:
Baltimore, 1956; Richmond, 1959; Washington D. C., 1961

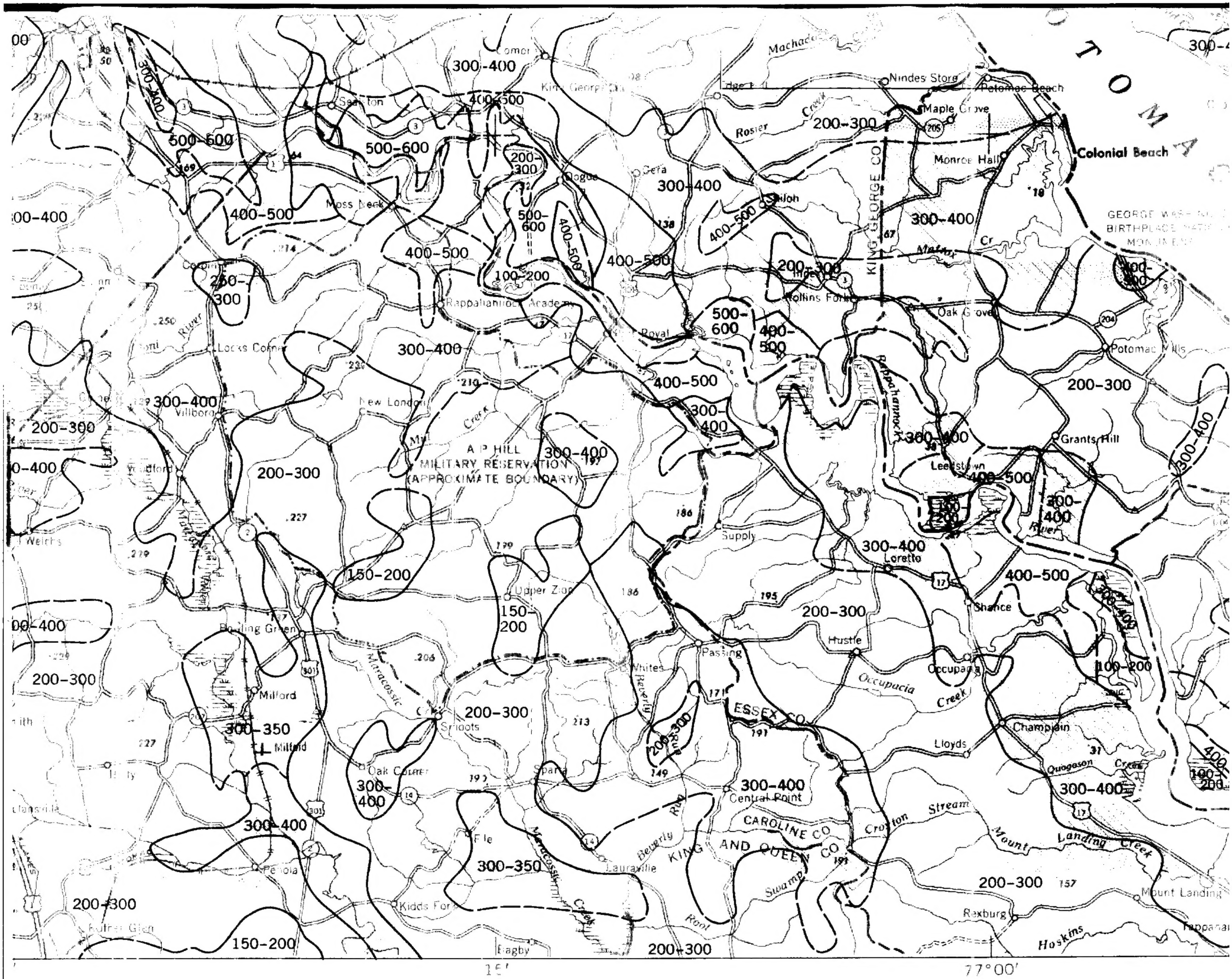
PLATE 1.—NATU

AN

N

MAGNETIC NORTH DEVIATES
FROM 5°15′ W TO 8°15′ W
WITHIN MAP AREA

AEC–CEX 59.4.17
GEOPHYSICAL INVESTIGATIONS
MAP GP–475



'URAL GAMMA AERORADIOACTIVITY OF THE
.ND PARTS OF MARYLAND, VIRGINIA, AND W

By

Sherman K. Neuschel

SCALE 1:250 000

5 0 5 10 15 20

5 0 5 10 15 20 25 KILOMETER

1965

45'

30'

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D. C.—1965—G64296

Aeroradioactivity survey r
above the ground, 1960

THE DISTRICT OF COLUMBIA
WEST VIRGINIA

20 25 MILES

KILOMETERS

mask the differences in radioactivity levels that reflect changes in the ground component.

The ground component comes from approximately the upper few inches of the ground. It consists of gamma rays from natural radionuclides, principally members of the uranium and thorium radioactive decay series and potassium-40, and fallout of radioactive nuclear fission products. Locally the amount of fallout, if present, must be small as the lowest total radiation measured is 100 counts per second in areas not affected by absorption of gamma rays by water. The distribution of fallout in the area surveyed is assumed to be uniform.

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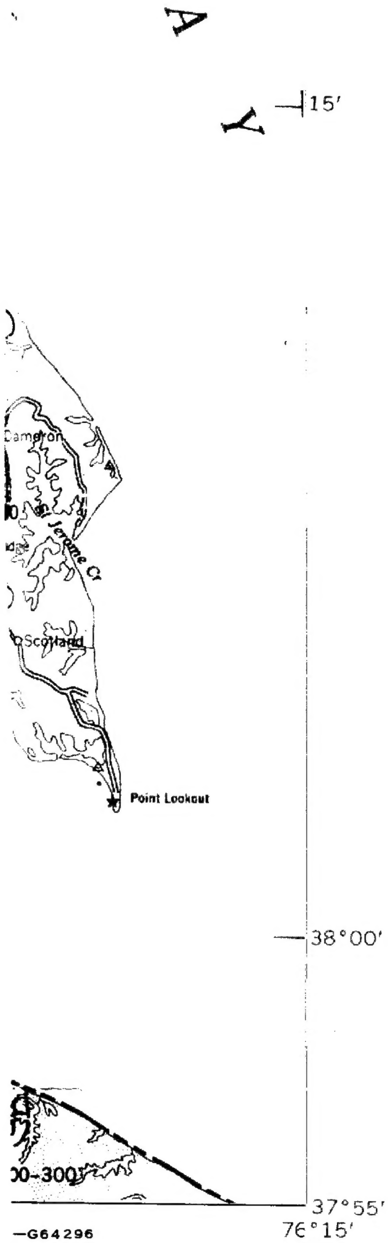
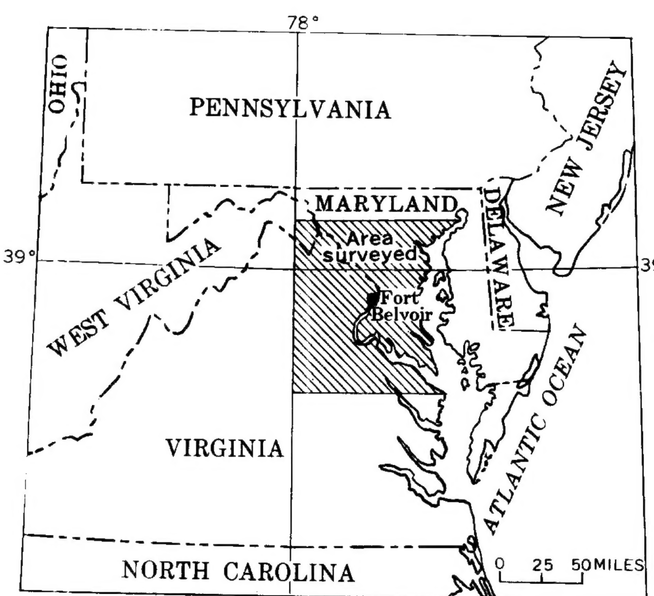


tivity survey made at 500 feet
round, 1960



INDEX MAP

Map obtainable from U.S. Geological Survey, Washington, D. C. 20242
Price 75 cents